TEMPERATURE-SALINITY RELATIONSHIPS IN THE SURFACE LAYERS OF THE EASTERN GULF OF MEXICO IN AUGUST 1966

A Thesis

By

JOHN ALEXANDER KLEIN BIRCHETT III

Lieutenant, United States Navy

Submitted to the Graduate College of the
Texas A&M University in
partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 1967

Major Subject: PHYSICAL OCEANOGRAPHY

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Approved as to style and content by:

(Chairman of Committee)

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A B S T R A C T

A two-week cruise in the Eastern Gulf of Mexico using continuous profile recording salinity/temperature/depth (STD) equipment as the primary means for acquiring in situ data provides the basis for an examination of the water masses and circulation features present during August, 1966. Attention is focused on the upper 300 meters.

Caribbean waters flowing in through the Yucatan Strait interact with resident Gulf of Mexico waters to create a dumb-bell shaped circulation pattern in the deeper waters of the Eastern Gulf. A large, well-developed, anticyclonic Northern Loop centered near 26° N., 88° W. dominates the circulation. An elongated anticyclonic smaller loop extends north-northwestward from the western tip of Cuba (Cuban Loop). The water masses in these circulation patterns are delineated into three distinct kinds based on significant characteristic temperature versus salinity relationship differences in the upper 300 meters.

The Eastern Gulf Loop waters are categorized as Right-Hand (of the loop flow) and Left-Hand waters. The former is practically identical to the inflowing Yucatan Current waters. While the characteristic water mass of the western Gulf of Mexico is similar to the Left-Hand waters, there are sufficiently distinctive differences to warrant its classification as a unique intermediate water mass between the Right-Hand and Left-Hand waters.

The adaptability and performance evaluation of the STD equipment in quasi-synoptic oceanographic surveying is also presented.

A C K N O W L E D G M E N T S

I am indebted to Dr. Dale F. Leipper for his academic and professional guidance in the preparation of this thesis and for his enthusiasm and personal interest during my tenure in this scholastic atmosphere. The method of treatment of the Gulf of Mexico waters contained herein is his suggestion, without which the completion of this paper would still be forthcoming.

I am grateful also to unknown personnel of the United States Navy who dictated my presence at Texas A&M University; without their decision I would yet be blindly seeing my professional habitat.

My most profound thanks, however, are directed to my family. Their patience and understanding made the arduous hours spent away from them pass quickly.

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LIST OF SYMBOLS AND ABBREVIATIONS

A, B, C	Empirical coefficients in relation of conductivity as a function of temperature.
cm/sec	Velocity measure, centimeters per second.
D	Geopotential (dynamic height) anomaly (dynamic meters).
db	Pressure measure, decibars.
dyn. m.	Dynamic meters.
G	Conductivity.
h	Vertical separation between temperature and salinity probes of STD sensor unit.
K_G	Conductivity coefficient.
K_R	Conductivity ratio coefficient.
km.	Linear measure, kilometers (1 kilometer = 0.538 nautical miles).
kts.	Velocity measure, nautical miles per hour (1 kt. = 51.5 cm/sec).
m.	Linear measure, meter(s).
m^3/sec	Volume transport measure, cubic meters per second.
n.m.	Linear measure, nautical miles (1 n.m. = 1853 m.).
Q	Transport function for geopotential volume flow.
R	Conductivity ratio.
S	Salinity (°/oo).
S*	Uncorrected or indicated salinity from STD salinity sensor (°/oo).
SAIW	Subantarctic Intermediate Water.
STD	Salinity/Temperature/Depth continuous _in situ_ recording equipment.
SUW	Subtropical Underwater.

T	Temperature (° C.).
V	STD sensor unit descent rate (meters per second).
Z	Vertical coordinate (meters or decibars).
α, β, δ	Empirical coefficients in relation for conductivity ratio as a function of salinity.
σ_t	Sigma-t, density parameter; a function of salinity and temperature as related to atmospheric pressure.
° C.	Degrees Celsius (degrees Centigrade).
%	Percent.
°/oo	Parts per thousand; parts per mille.
° N.	Degrees of North latitude.
° W.	Degrees of West longitude.
'	Minutes (arc measure) of latitude and longitude.

CHAPTER I

INTRODUCTION

A. Historical Remarks

An hydrographic analysis of Gulf of Mexico waters was conducted by Parr in the late 1930's, and his conclusions (1935a,b; 1937a,b; 1938) were until recently (Wennekens, 1959) the only detailed study of the temperature and salinity structure of Gulf waters. Parr's oceanographic data, however, were meager, as there were few deep water measurements obtained (Leipper, 1954).

Dietrich (1939) subsequently described in his classical survey of the American Mediterranean the presence of an Eastern Gulf clockwise loop current, formed by the meandering of the Yucatan Current as it progressed from the Caribbean Basin to the Straits of Florida. Dietrich's chart of surface current patterns was based on a description (by Bjerknes) of movements of American shipping in the Gulf in 1905 and 1906 and of English shipping for the Caribbean area, and on American pilot charts. Although the circulation pattern depicted was deduced from the study of surface measurements in the Gulf, and includes wind-driven effects, it was taken to be representative of the general circulation within the surface layers.

A large, well-defined anticyclonic surface loop was observed in the Eastern Gulf on three cruises conducted during 1951-1952 by the Texas A&M Research Foundation and the United States Fish and Wildlife Service. These cruises provided the first partial coverage of the

Gulf with information needed to compute deep water currents; subsequent analysis revealed that the deep water data supported the general surface circulation pattern described by Parr and Dietrich (Leipper, 1954). A 1954 summer cruise was conducted (by the Texas A&M Research Foundation) specifically to study the loop current. That cruise (Austin, 1955) supplied descriptive hydrographic data, including dynamic height analyses and temperature-depth and oxygen-depth profiles across the loop, clearly depicting its presence. Austin concluded that the loop was a common feature of the Yucatan Current-Gulf Stream system, that it was centered at approximately 26° N., 86° W. (at the time of his summer cruise), and that it varied in size, shape, and intensity in time and space.

B. Present Status of Knowledge

Observation of time and space variability of the loop since 1954 has been recorded in several winter and summer cruises in the Eastern Gulf (McLellan, 1960; Gaul, 1967; Leipper, 1967; Nowlin and McLellan, 1967) and adjacent waters (Cochrane, 1961, 1962, 1963, 1965, 1966). Wust's work (1964) is an exacting analysis of the Caribbean source waters of the Eastern Gulf, while Cochrane's investigations of the Yucatan Current offer a description of this water at its point of introduction into the Gulf basin. Nowlin and McLellan (1967) have presented their results from a rapid winter survey of the entire Gulf of Mexico in 1962; their attention is focused on the circulation regions of the Eastern and Western Gulf sections, and considerable

discussion is devoted to the Eastern Gulf Loop Current system.

Thus, while considerable hydrographic data is presently available for an objective analysis of the shallow layers of the loop waters, no treatments of water mass description primarily directed at the upper 300 meters of these waters have been made.

C. Objectives

An August, 1966 cruise in the Eastern Gulf of Mexico is investigated in order to describe on a synoptic basis the temperature, salinity, and density characteristics of the surface waters (upper 300 meters) located over the deeper portions of the Eastern Gulf basin; to define the water masses present in the Eastern Gulf Loop flow based on characteristic temperature versus salinity relationships in the upper 300 meters; to determine to what extent the presence of these water masses may be indicated by sea surface temperature and/or salinity alone; and to analyze the effectiveness of the salinity/temperature/depth (STD) continuous profile recording equipment as a primary means of oceanographic data collection.

CHAPTER II

OBSERVATION

A. Background

The Eastern Gulf waters, in general, have been surveyed several times, as referenced previously; most of the resulting studies were directed toward the Gulf circulation and dynamics (especially for the deeper waters) or were a composite compliation of data from several cruises over a period of several years. A quasi-synoptic approach, such as that of Nowlin and McLellan (1967), permits a more meaningful interpretation of specific characteristic features of the Eastern Gulf and its loop current system; however, there was but one early cruise (Austin, 1955) approaching a near-synoptic representation of conditions in the late summer season -- the season during which the East Gulf loop has its maximum intrusion into the Gulf, at least in certain years (Leipper, 1967). Any analysis which is dependent upon the combination of data from various years and seasons is certain to be misleading, especially in the surface layers, since Gulf currents show great variation in position.

With these thoughts foremost, an analysis of a recent late summer cruise (ALAMINOS 66-A-11, August 4-18, 1966, conducted by Dr. D. F. Leipper) was undertaken. The author participated in this cruise.

B. Cruise Execution

Pre-cruise planning for ALAMINOS 66-A-11 was significant in that

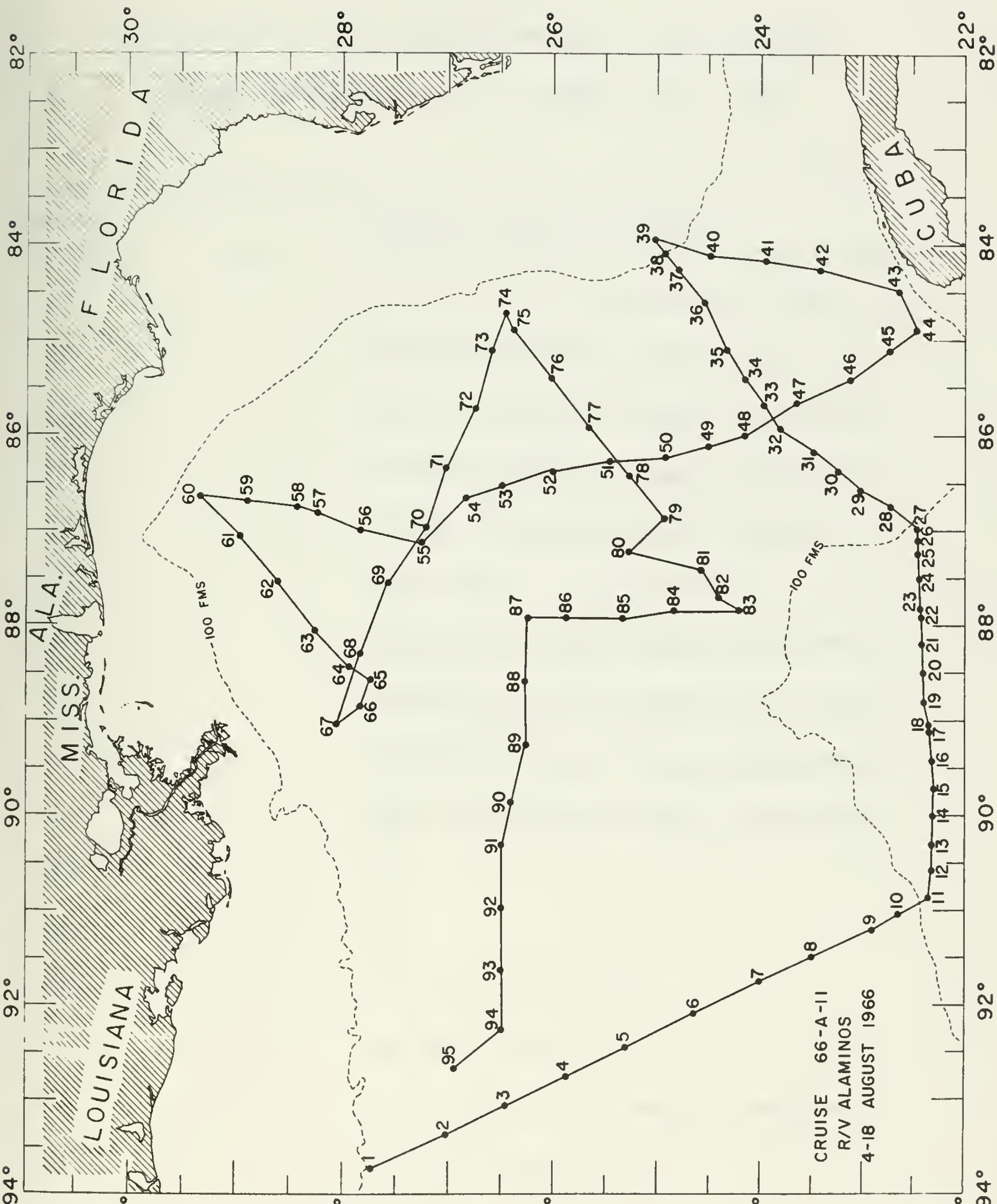
station locations were not predetermined; rather, the objective of the cruise was to seek, find, and investigate as thoroughly as possible within the limited ship time available the Eastern Gulf Loop Current. 66-A-11 accomplished its mission. The final cruise track (Figure 1) suggests the thoroughness with which the current was traced. It should be noted that the elapsed time of the significant data gathering period was less than two weeks, a fact which lends credence to synoptic treatment of the assembled data.

C. Data Collection

Cruise 66-A-11 was unique in that a Hytech Model 9006 salinity/temperature/depth continuous profile recorder (STD) was utilized for collecting nearly all *in situ* salinity and temperature data for the cruise. Discussion of the instrument's utility and performance evaluation is given in Appendix A. Classical hydrocasts (using Nansen bottles with reversing thermometers) were made during the initial course leg of the cruise (see Fig. 1) and at several subsequent locations (Table I); their data were used primarily as "reference" values of temperature and salinity, at selected depths, to which the STD analog trace (paper graph) and digital (punched tape) outputs were compared for immediate "on station" performance evaluation and subsequent error analysis.

Hourly and "on station" bathythermograph casts and observations of surface temperature and salinity provided supplemental information for comparison with the STD measurements.

FIGURE 1. STD stations occupied during ALAMINOS 66-A-11, 4-18 August 1966. Lines indicate ship's track.



CRUISE 66-A-11
R/V ALAMINOS
4-18 AUGUST 1966
LOUISIANA
MISS.
ALA.
FLORIDA
CUBA
100 FMS
100 FMS
30°
28°
26°
24°
22°
82°
84°
86°
88°
90°
92°
94°

FIGURE 1

TABLE I

DESIGNATION OF COINCIDENT HYDROCAST - STD STATIONS

CRUISE ALAMINOS 66-A-11 AUGUST 4-18, 1966

Station	Sampling Depths, Meters
1**	0, 15, 25, 50, 75, 100, 125, 150, 175
2	0-1002 (Deep Cast Sample Levels***)
3	0-996 (Deep Cast Sample Levels***)
4	0-1000 (Deep Cast Sample Levels***)
5	0-1198 (Deep Cast Sample Levels***)
6	0, 50, 75, 125, 175, 300
7	0-1199 (Deep Cast Sample Levels***)
8	0-1187 (Deep Cast Sample Levels***)
9	0-1198 (Deep Cast Sample Levels***)
10	0-800 (Deep Cast Sample Levels***)
15*	22
16*	23
53*	15, 399, 802, 1199
54*	15, 408, 760, 1171
55	0-1201 (Deep Cast Sample Levels***)
56*	15, 410, 778, 1180
57*	15, 465
59*	8, 453
61*	25, 406

TABLE I (continued)

DESIGNATION OF COINCIDENT HYDROCAST - STD STATIONS

CRUISE ALAMINOS 66-A-11 AUGUST 4-18, 1966

Station	Sampling Depths, Meters
62*	790
63*	810
65*	600
66*	400
68*	190
75*	1196
78*	949
81*	400

** No STD Cast

* Nansen Bottles Attached to STD Cable

*** Deep Cast Sample Levels: 0, 50, 100, 150, 200, 300, 400, 500, 600, 800, 1000, 1200.

"Surface" temperature and salinity observations were made by direct sampling at a nominal depth of one meter below the air-sea interface to prevent the distortion of this data by the influence of short-term variations, viz., wind-influenced property transfer processes.

Observations of oxygen and phosphate concentrations of the water masses were not made. Attachment of sampling bottles to the STD cable at each station would have virtually doubled station occupancy time and would have further limited the coverage of the Eastern Gulf Loop Current waters within the alloted time period.

D. Measurements

Salinity (chlorinity) determinations of all water samples were conducted as soon as possible after collection, utilizing a shipboard conductive salinometer built at the University of Washington.

Temperatures and sampling depth levels of the Nansen bottle hydrocasts were determined following standard oceanographic data processing techniques (LaFond, 1951).

Accuracy of these measurements can be shown to be within the established limits, i.e., $\pm$ 0.02 parts per mille in salinity, $\pm$ 0.02° C. in temperature, and $\pm$ 5 meters in depth (Sverdrup et.al., 1942). The prima facie acceptance of the values of these measurements is of paramount importance to the correction of STD measurements and subsequent interpretation of dynamic computations and graphical analyses based on STD data (see Appendix A.).

CHAPTER III

PRESENTATION AND ANALYSIS OF DATA

A. Terminology

The Eastern Gulf Loop Current is directly caused and maintained by the influx of the Yucatan Current into the Gulf of Mexico via the Yucatan Strait. The representative temperature versus salinity relationship of the Right-Hand portion of this inflowing Yucatan Current is given by Wust (1964: Fig. 3); a distinctive feature is the subsurface salinity maximum near 22.5° C. and 36.75°/oo (Subtropical Underwater - SUW). Wennekens (1959: Fig. 3A) also terms this water "Yucatan Water" and likewise illustrates the salinity maximum feature at a depth of about 200 meters. The nomenclature of Nowlin and McLellan (1967) is herein adopted for designation of such water within the confines of the Gulf of Mexico basin: Eastern Gulf Loop water. This water mass remains remarkably uniform during its traverse through the Gulf; so much so, in fact, that the "core" of Subtropical Underwater remnant of the Yucatan Current may be used as an index of its location. The surrounding waters of the Gulf are modified in varying degrees dependent upon the intensification or degradation of the inflow and the extent of development of the Loop northward into the Gulf; however, a subsurface salinity maximum of approximately 36.4°/oo determines the demarcation between distinctive Eastern Gulf Loop waters and other Gulf of Mexico waters.

It must be emphasized at this point that the data presented

herein and inferences and subsequent conclusions based thereon are considered to be representative only of conditions in the Gulf of Mexico during early August, 1966, unless otherwise specified.

Subsequent discussion of salinity, temperature, density, and related water mass properties involves delineation of "Right-Hand" or "Left-Hand" categorization of the waters at each station. Right-Hand waters exhibit a temperature-salinity correlation commensurate with the typical Yucatan Current T-S curve, and such waters are representative of the right side of the flow around the loop, facing downstream. Left-Hand waters exhibit a distinctively different T-S correlation which defines these waters above 300 meters and is indicative of the left side of the loop flow, facing downstream. The above nomenclature serves well to quickly separate the waters at the various stations into two major groupings useful in the study of the location of the current.

Further, the resemblance of this terminology to Stommel's description (1965, p. 21) of the Gulf Stream is not coincidental:

> "The Gulf Stream is not a river of hot water flowing through the ocean, but a narrow ribbon of high-velocity water acting as a boundary that prevents the warm water on the Sargasso Sea (right-hand) side from over-flowing the colder, denser waters on the inshore (left-hand) side."

B. Characteristic T-S Relationships

<u>1. Right-Hand Eastern Gulf Loop Waters</u>. Figure 2 shows the composite temperature versus salinity relationship for all ALAMINOS 66-A-11 stations exhibiting water mass properties typical of the

FIGURE 2. Characteristic temperature versus salinity relationship for Right-Hand Eastern Gulf Loop Water. Mean depths (in meters) of observation of temperature-salinity values shown (dots) are noted alongside curve.

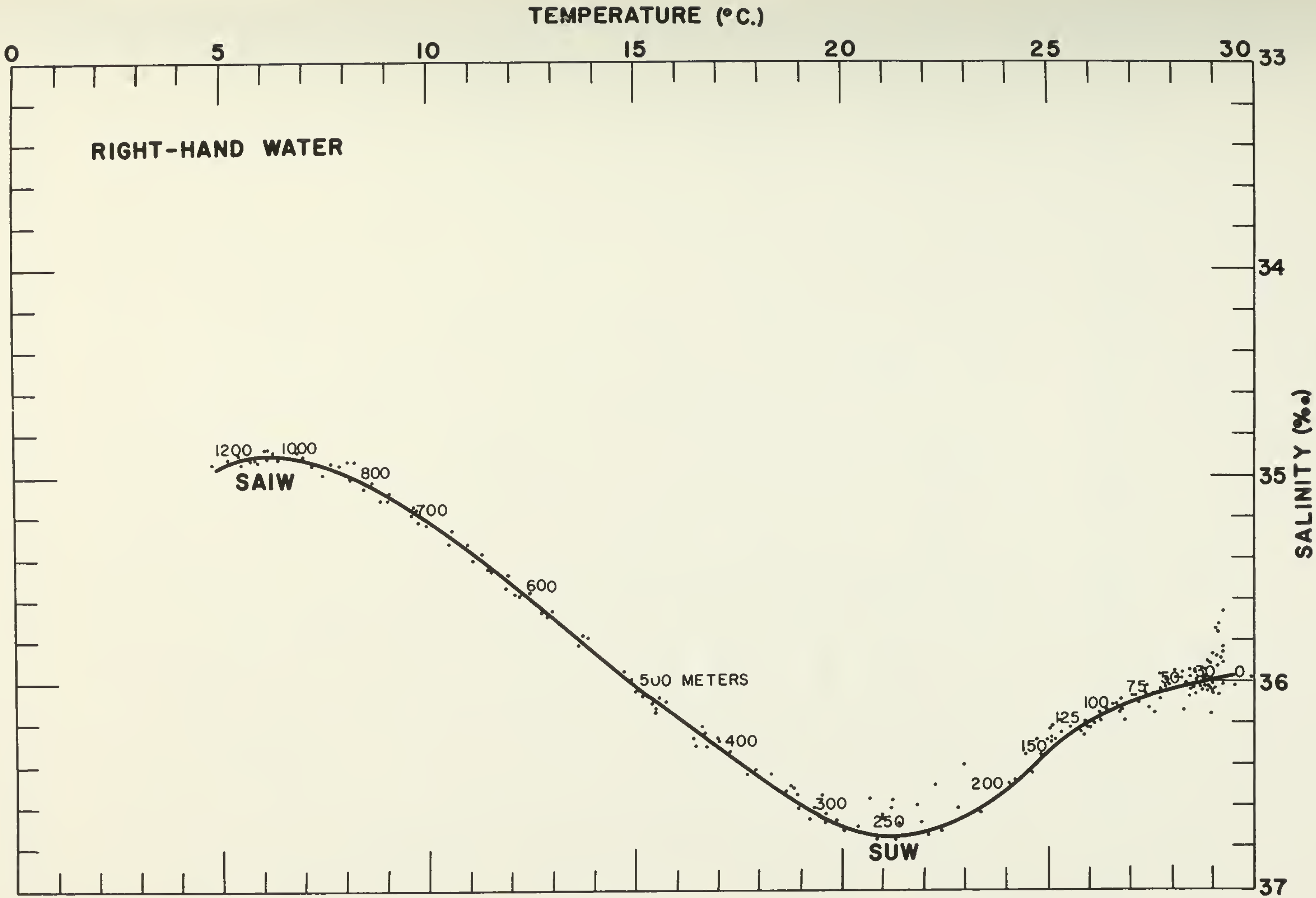

TEMPERATURE (°C.)
0
5
10
15
20
25
30
SALINITY (‰)
33
34
35
36
37
RIGHT-HAND WATER
SAIW
SUW
500 METERS
0
75
100
125
150
200
250
300
400
600
700
800
1000
1200

FIGURE 2

Right-Hand waters of the Eastern Gulf Loop Current. Table II summarizes the mean values of this composite T-S relationship at standard depth levels. (Reference to standard depths in this paper signifies sampling levels of 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 1000, and 1200 meters, unless otherwise specified.)

The T-S relationship for Right-Hand waters is practically identical to the characteristic T-S relationship for the Caribbean Basin waters as shown by Wust (1964: Fig. 3). The salinity minimum of 34.88°/oo at 6.1°C. is clearly related to the remnant of Sub-Antarctic Intermediate Water (SAIW), which has nominal values in the Caribbean of 34.75°/oo at 6.3° C. A maximum subsurface salinity value of 36.74°/oo at 21.2° C. is likewise practically coincident with the Subtropical Underwater (SUW) of Wust's Caribbean T-S curve. Above 22°C., however, the Right-Hand waters exhibit a marked departure from the Caribbean Basin T-S curve. The shape of the Right-Hand water T-S curve from 21° C. to 24° C. is the mirror image of the curve from 21° C. to about 18° C.; the temperature extremities of this segment are coincident with the 36.4°/oo isohaline. Near 25° C. the curve reverses slope to represent the relatively uniform salinity (approximately 35.9-36.0°/oo from 28-29° C.) of the surface layers (upper 50 meters) typical of late summer-early fall conditions in the Gulf of Mexico. Note the perpendicularity of the curve to the isopycnals at 26° C.

The portion of the curve from 5° C. to about 17° C. coincides

TABLE II

RIGHT-HAND EASTERN GULF LOOP WATERS

CRUISE ALAMINOS 66-A-11 AUGUST 4-18, 1966

Depth, Meters	Temperature, °C.	Salinity, 0/00	Sigma-t
0	29.2	35.86	22.6
10	29.2	35.86	22.7
20	29.2	35.92	22.7
30	29.0	36.04	22.9
50	28.5	36.07	23.1
75	27.6	36.15	23.4
100	26.7	36.13	23.7
125	25.7	36.19	24.1
150	25.2	36.28	24.3
200	24.1	36.52	24.8
250	21.5	36.68	25.7
300	19.4	36.60	26.2
400	17.4	36.37	26.5
500	15.4	36.06	26.7
600	12.6	35.60	27.0
700	10.3	35.27	27.1
800	8.7	35.03	27.2
1000	6.6	34.89	27.4
1200	5.5	34.90	27.6

Stations From Which The Above Data Were Compiled:
30, 31, 32, 33, 34, 35, 41, 42, 43, 44, 45, 46, 47, 48, 49, 54, 55, 56, 69, 70, 71, 79, 80, 81, 85, 86, 87, 88, 89, 90.
(For locations of stations, refer to Figure 1)

with the usual T-S configuration for the Gulf basin waters. Above 17° C. the significant features described above distinguish this Right-Hand water from its source Yucatan (Caribbean Basin) water.

The nominal depth of the subsurface salinity maximum is about 200 meters; Wennekens (1959) also has found 200 meters to be the approximate location of the salinity maximum (SUW remnant). Nowlin and McLellan (1967) specify a depth of 150 meters. Wenneken's data cover the summer season, while Nowlin and McLellan's data is representative of winter conditions in the Gulf. In winter, these waters, existing as an elongated loop northwest of Cuba (Nowlin and McLellan, 1967), are located over the moderately deep waters of the southeastern basin of the Eastern Gulf; the entering Yucatan waters move swiftly around the loop and exit the Florida Straits without expanding in breadth and depth. Conversely, in summer-fall, the Loop extends well northward over the deeper waters of the central basin of the Eastern Gulf (Leipper, 1967).

2. Left-Hand Eastern Gulf Loop Waters. Figure 3 shows the composite temperature versus salinity relationship for the ALAMINOS 66-A-11 stations exhibiting water mass properties typical of the Left-Hand waters of the Eastern Gulf Loop Current. Table III summarizes the mean values of the composite T-S relationship at standard depths.

The T-S relationship for Left-Hand waters is coincident with the T-S relationship for the Right-Hand waters in the temperature range from 5° C. to about 17° C. In this temperature range, the waters of the Eastern Gulf Loop Current are very similar. (Compare Figs. 2

FIGURE 3. Characteristic temperature versus salinity relationship for Left-Hand Eastern Gulf Loop Water. Mean depths (in meters) of observation of temperature-salinity values shown (dots) are noted alongside curve.

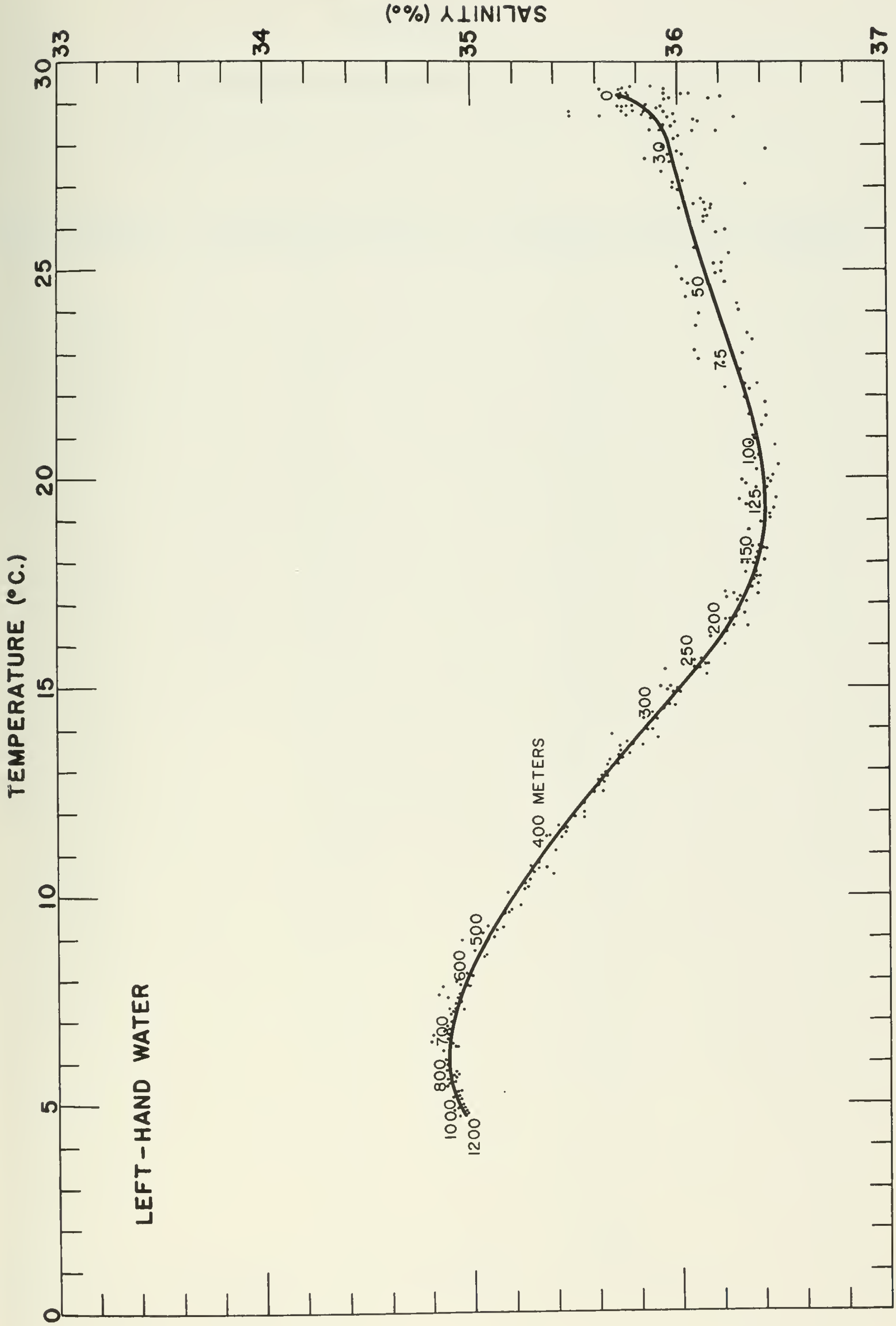

SALINITY (‰)
33
34
35
36
37
TEMPERATURE (°C.)
0
5
10
15
20
25
30
LEFT-HAND WATER
400 METERS
0
30
50
75
100
125
150
200
250
300
500
600
700
800
1000
1200

FIGURE 3

TABLE III

LEFT-HAND EASTERN GULF LOOP WATERS

CRUISE ALAMINOS 66-A-11 AUGUST 4-18, 1966

Depth, Meters	Temperature, °C.	Salinity, 0/00	Sigma-t
0	29.2	35.71	22.5
10	29.1	35.73	22.6
20	29.0	35.77	22.7
30	28.0	35.86	23.1
50	24.6	36.15	24.3
75	23.9	36.26	24.9
100	20.4	36.39	25.7
125	19.0	36.42	26.1
150	18.1	36.38	26.3
200	15.9	36.17	26.5
250	15.3	36.08	26.7
300	14.2	35.88	26.8
400	11.1	35.36	27.0
500	8.7	35.06	27.2
600	8.1	34.99	27.3
700	6.4	34.88	27.4
800	5.6	34.88	27.5
1000	5.0	34.93	27.6
1200	4.7	34.96	27.7

Stations From Which The Above Data Were Compiled:
28, 29, 36, 37, 40, 50, 53, 57, 58, 59, 64, 66, 67, 72, 73, 74, 75, 76, 82, 84, 91, 92, 93, 94.
(For locations of stations, refer to Figure 1)

and 3.)

In Left-Hand waters the Subtropical Underwater influence is evident to a slight degree, near 19.5° C., where the subsurface salinity maximum of approximately 36.4°/oo is reached. It is possible that the SUW remnant of the Right-Hand waters has diffused into other Gulf waters along the isopyncnal surfaces to form this most characteristic feature of the Left-Hand waters.

Left-Hand waters nearer the surface are characterized by significantly lower salinities (35.6-35.9°/oo) than exhibited in the Western Gulf T-S curve (36.2-36.4°/oo) and the Right-Hand T-S curve. (Compare Figures 2, 3, and 4.) From about 16.5° C., corresponding to a nominal depth of nearly 200 meters, to 27° C., at approximately 35 meters depth, these lower salinities of the Left-Hand waters may mix with the higher salinity SUW remnant of the Right-Hand waters to form the intermediate water mass of the Western Gulf (see Fig. 5).

The significant distinction between Left-Hand and Western Gulf waters lies in the temperature range from 20-26° C. While both waters have salinities near 36.4°/oo at 20° C., Left-Hand water salinities decrease markedly as temperature increases, yet the Western Gulf T-S curve is relatively flat (constant salinity) over the same temperature span.

One remarkable distinction between Left-Hand and Right-Hand waters is in the depths at which given values of the water mass properties are found. In all instances (except in the mixed layer) the properties of the Left-Hand waters are elevated above those of

FIGURE 4. Characteristic temperature versus salinity relationship for Western Gulf of Mexico Water. Mean depths (in meters) of observation of temperature-salinity values shown (dots) are noted alongside curve.

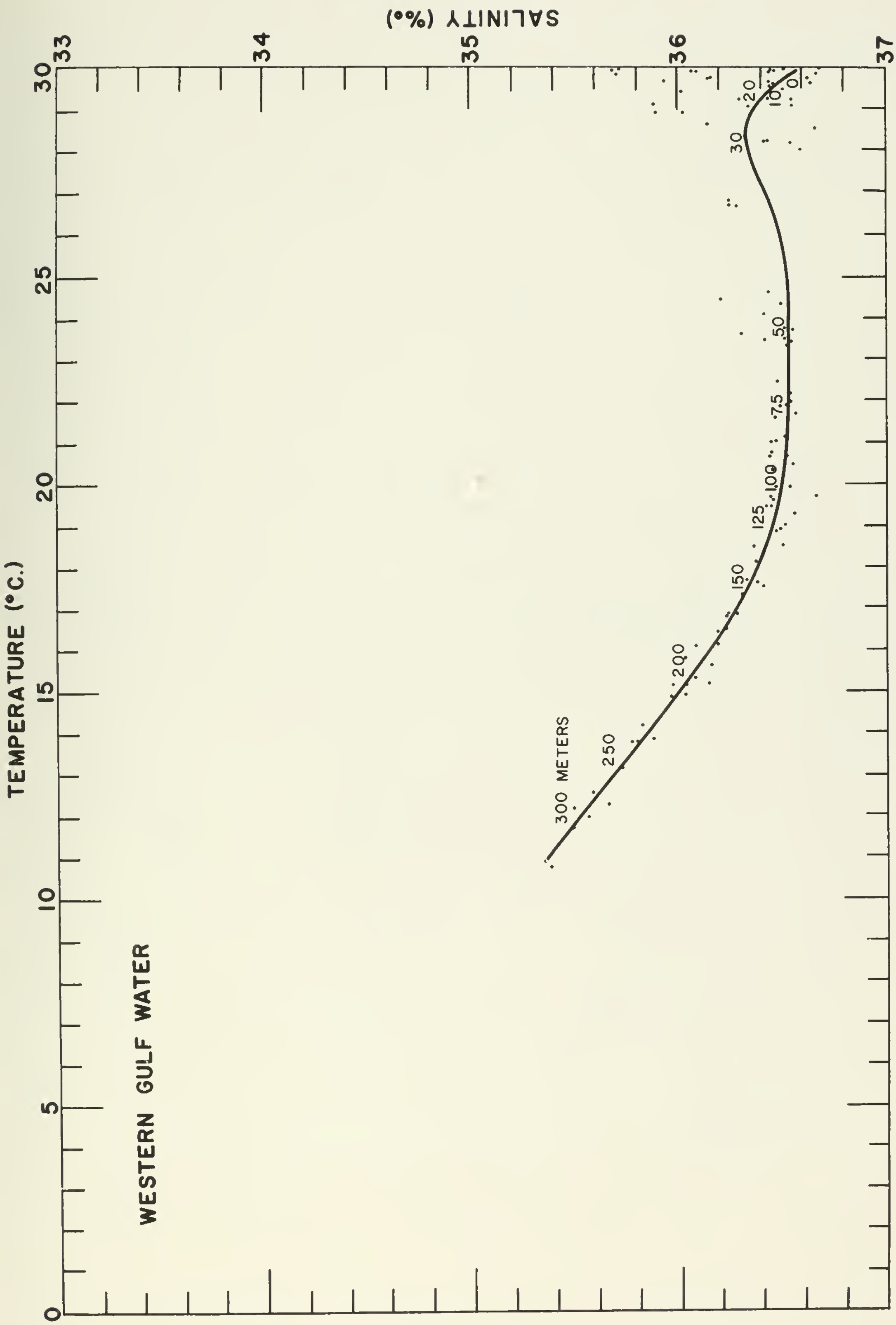

WESTERN GULF WATER
TEMPERATURE (°C.)
SALINITY (‰)
0
5
10
15
20
25
30
33
34
35
36
37
300 METERS
250
200
150
125
100
75
50
30
20
10
0

FIGURE 4

FIGURE 5. Superimposed characteristic temperature versus salinity relationships for Right-Hand, Left-Hand, and Western Gulf Waters for temperatures above 15° C. (upper 300 meters, approximately).

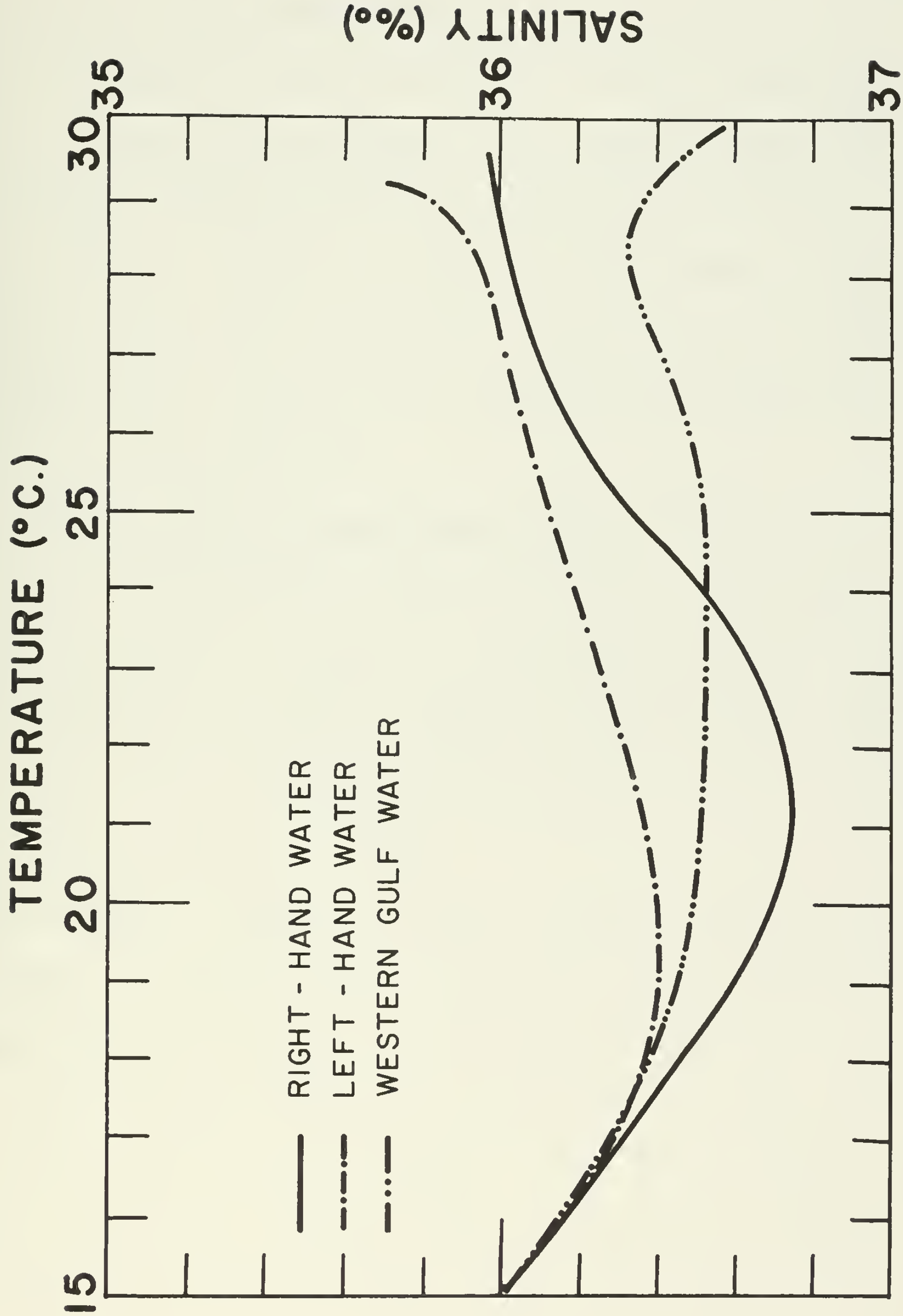

SALINITY (‰)
35
36
37
TEMPERATURE (°C.)
15
20
25
30
RIGHT - HAND WATER
LEFT - HAND WATER
WESTERN GULF WATER

FIGURE 5

equal magnitude in the Right-Hand waters, <u>i.e.</u>, the depth at which a given value of any mass property of the Left-Hand water is found is less than the depth at which the same value appears in Right-Hand water. For example, the differences in the depths at which equal values of sigma-t are found varies from 20 meters (at 28° C.) to 250 meters (at 16° C.). Further, the depths of the minimum salinity of the Left-Hand waters is some 300 meters shallower than its location in Right-Hand waters. Tables II and III facilitate comparison of the depths of other properties.

<u>3. Western Gulf and Campeche Bank Waters</u>. Stations 2 - 11, all west of 89° W. longitude, have characteristic T-S relationships as illustrated in Figure 4. Table IV tabulates the mean values of temperature and salinity at standard depths for these Western Gulf waters. This T-S curve is not unlike that for Western Gulf waters given by Wennekens (1959: Fig. 3B).

The temperature range of the upper 100 meters varies from 20-29° C., while the salinity (approximately 36.5°/oo) remains almost unchanged from 40-100 meters. Salinities decrease gradually from a surface value of about 36.5°/oo to a near-surface minimum of about 36.2°/oo at a depth of about 30 meters. Below this depth the salinity increases to a maximum subsurface value of 36.48°/oo at about 50 meters depth. The high salinities in the upper 50 meters are attributed to increased seasonal evaporation and convective mixing of these waters in the Western Gulf.

The unorganized T-S data points (Figure 6) of the Campeche Bank

TABLE IV

WESTERN GULF WATERS

CRUISE ALAMINOS 66-A-11 AUGUST 4-18, 1966

Depth, Meters	Temperature, °C.	Salinity, 0/00	Sigma-t
0	30.0	36.55	22.9
10	29.7	36.44	23.0
20	29.3	36.34	23.1
30	28.5	36.29	23.4
50	23.8	36.49	24.8
75	22.0	36.48	25.6
100	20.2	36.46	26.0
125	19.1	36.41	26.3
150	17.6	36.29	26.5
200	15.4	36.04	26.8
250	13.2	35.65	26.9
300	11.9	35.45	27.0

Stations From Which The Above Data Were Compiled:
2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 51, 52, 65, 68, 78, 83, 95.
(For locations of stations, refer to Figure 1)

stations (Stations 12-27) reveal no significant pattern; the congregation of several points near 36.1°/oo and 29° C. (surface values) may be associated with the seasonal evaporation and wind-stirring of these shallow shelf waters.

4. General. For the cruise of August, 1966, the T-S curve for a given station is readily classified as either Right-Hand or Left-Hand water using criteria and definitive temperature and salinity values presented above. Transition from one water mass to the other, when occurring, is accomplished between only a few stations. (Average distance between stations on this cruise was 30 n.m.) Even though the marked depth differences in the properties of these two water masses are not apparent in their characteristic T-S curves, use of the T-S relationship alone is a practical means of determining the boundaries of the Eastern Gulf Loop Current.

Wennekens (1959) defines the water mass in the shallow Eastern Gulf as "Continental Edge Water". It has a T-S relationship similar to the Left-Hand Eastern Gulf waters defined above. He notes "the great reduction of the salinity maximum..." in "... the upper portion of the curve ..." having "... salinities ranging between 36.1°/oo and 36.6°/oo". The summer temperature range of the Edge Water was found to be from 30° C. (at the surface) to 20° C. (at 100 meters). He concluded that the "differentiation between the Edge Water and Yucatan Water is found mainly in the upper 300 m. Below about 300 m., both (have) T-S characteristics (which) merge within a single narrow envelope".

FIGURE 6. Temperature versus salinity values for Campeche Bank Waters. Dots represent observation points.

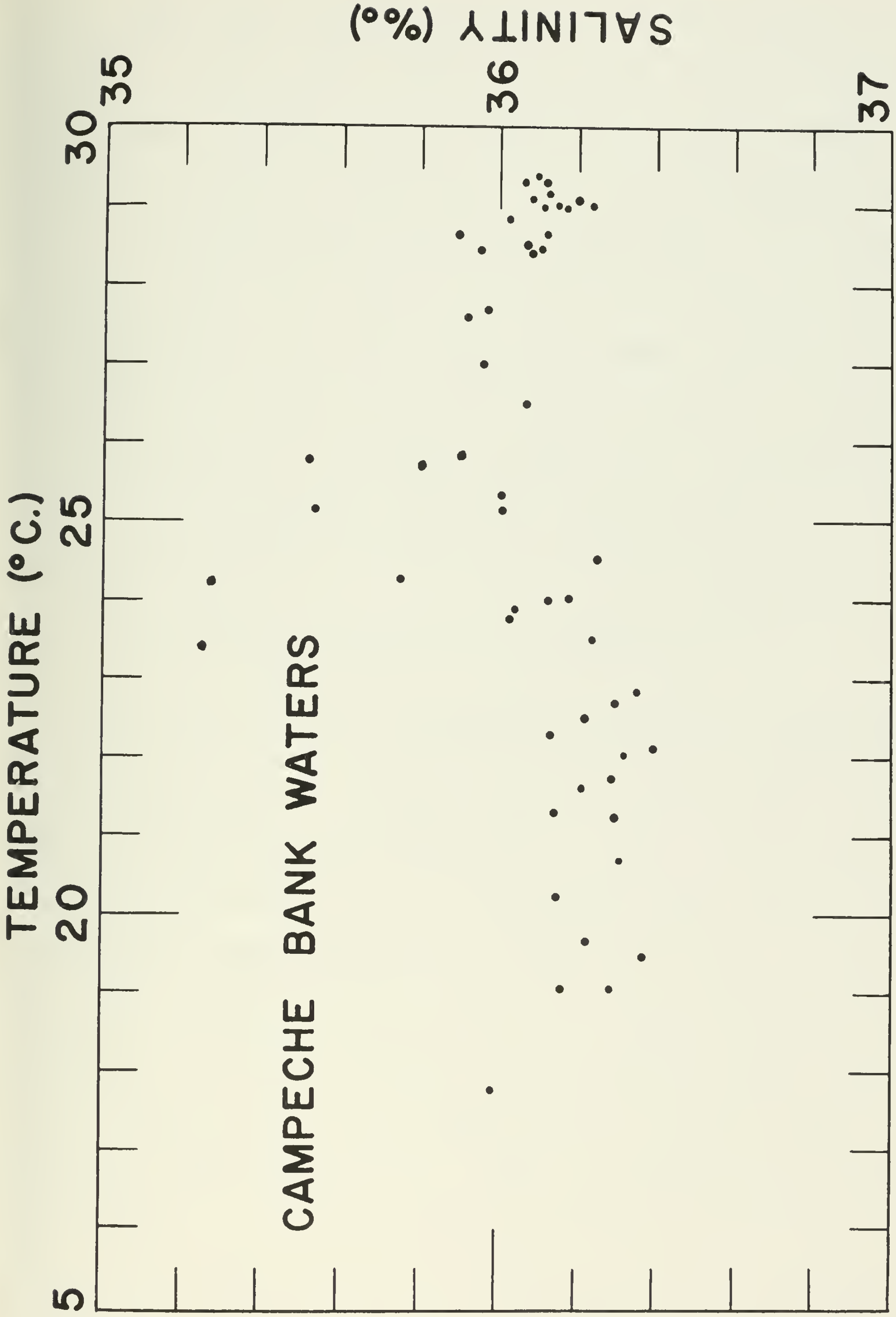

SALINITY (‰)
35
36
37
TEMPERATURE (°C.)
30
25
20
15
CAMPECHE BANK WATERS

FIGURE 6

For this August cruise, the differences in the magnitudes of the subsurface salinity maxima between the Right-Hand and Left-Hand waters are even more significant than the differences between Wennekens' Yucatan and Continental Edge waters. (See especially Wennekens, 1959: Fig. 4.) While Wennekens categorizes his Edge Water as the intermediate water mass between Yucatan Water and Western Gulf water (a water mass unmodified by the Yucatan Water and resident west of a line connecting the Mississippi delta and the Yucatan Peninsula), it would appear that, based on the findings of this cruise, the Western Gulf waters are the intermediate water mass possibly formed by the combination of the Right-Hand and Left-Hand water mass properties.

C. Surface Temperatures and Salinities

An attempt was made to determine the presence of the Right-Hand and Left-Hand waters of the Eastern Gulf Loop Current based on the observed surface temperature and salinity values. On the premise that the warm, high-salinity core of the Right-Hand waters would be evident in relatively warmer temperatures and higher salinities at the surface, while the Left-Hand waters would not be so significantly represented by their surface values of temperature and salinity, a simple plot of surface salinity versus temperature was prepared (Figure 7). Nearly all Right-Hand waters fell within the ranges of 35.77-36.0°/oo and 29-29.8° C., while the majority of Left-Hand waters were outside these ranges. However, there were sufficient stations of definite Left-Hand water characteristics plotting within the range of Right-

FIGURE 7. Observed surface values of temperature versus salinity for selected stations, ALAMINOS 66-A-11, 4-18 August, 1966. Open circles are Left-Hand Water stations; dots are Right-Hand Water stations. Numbers indicate STD stations. For station locations, see Figure 1.

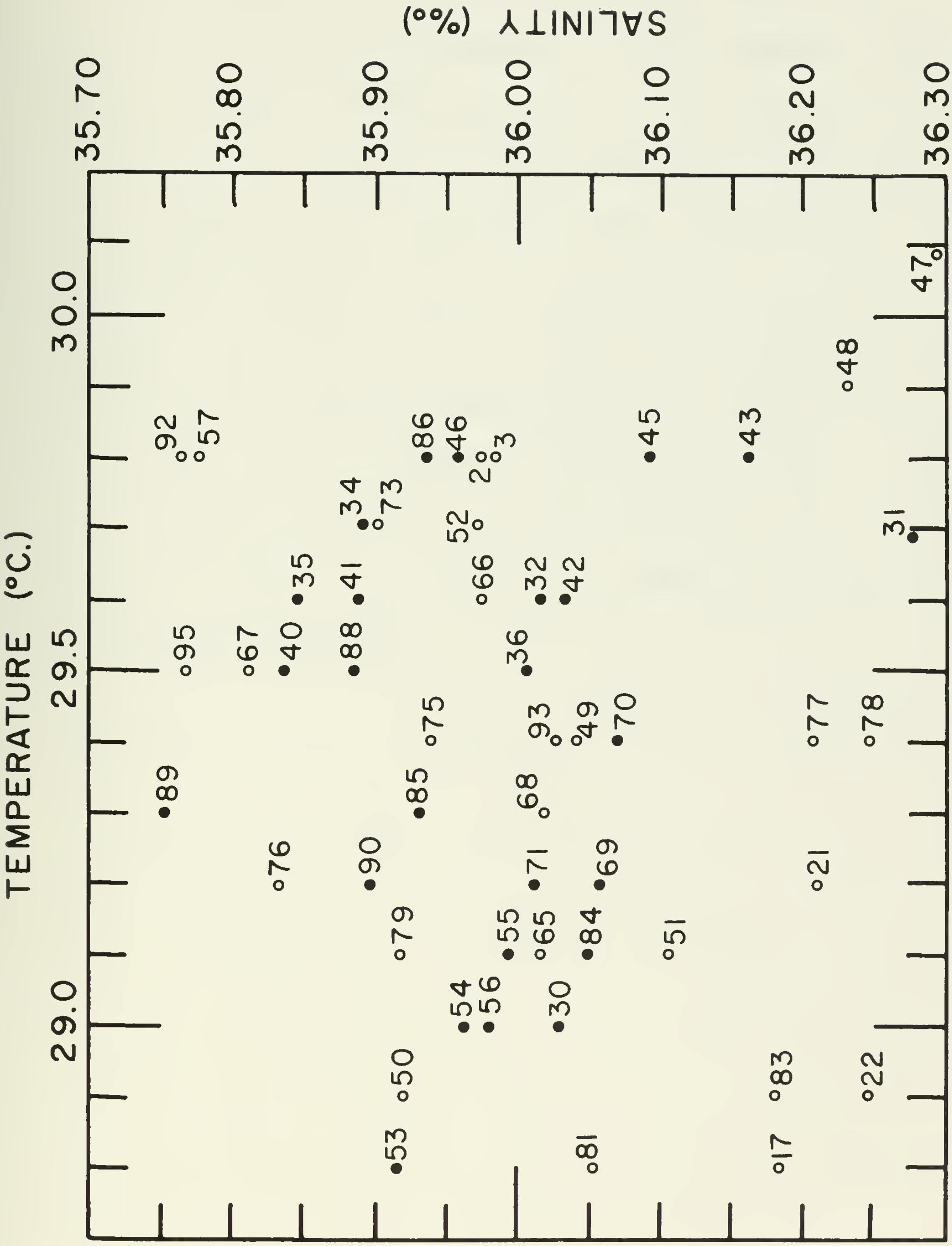

TEMPERATURE (°C.)
29.0
29.5
30.0
SALINITY (‰)
35.70
35.80
35.90
36.00
36.10
36.20
36.30

FIGURE 7

Hand waters to cast doubt on judgments based on the limiting values stated above. In fact, there were a few stations representing Western Gulf waters which also fell within the Right-Hand water limits!

The explanation of these paradoxical results lies in the seasonal depth of the mixed layer. Of at least 30 meters depth, and often deeper, as observed at the time of this cruise, the late summer mixed layer effectively masks the temperature and salinity structure of the underlying waters. The Left-Hand waters are practically indistinguishable from the closely-related Western Gulf waters in the analysis of their surface temperature and salinity values. Surface values of temperature and salinity falling within the ranges determined for the period of this cruise can be termed as only suggestive of Right-Hand waters beneath.

D. Temperature, Salinity, and Sigma-t in the Vertical Sections

The temperature, salinity, and sigma-t profiles in the vertical sections for several cross-current legs are presented as Figures 9 through 23. Figure 8 shows the transects approximating these cross-current legs for this cruise. These vertical sections represent the most significant portrayal of the Eastern Gulf Loop Waters and have been selected (based on specific features particularly relevant to the description of the Right-Hand and Left-Hand waters) from all such sections prepared from the data for this August cruise.

In the following discussion, inference of currents in the upper 1000 meters based on temperature and salinity (and hence density)

FIGURE 8. Transects of several course legs of ALAMINOS 66-A-11, 4-18 August 1966. Vertical sections discussed in text correspond to these transects. See Figure 1 for correspondence of transects with station locations.

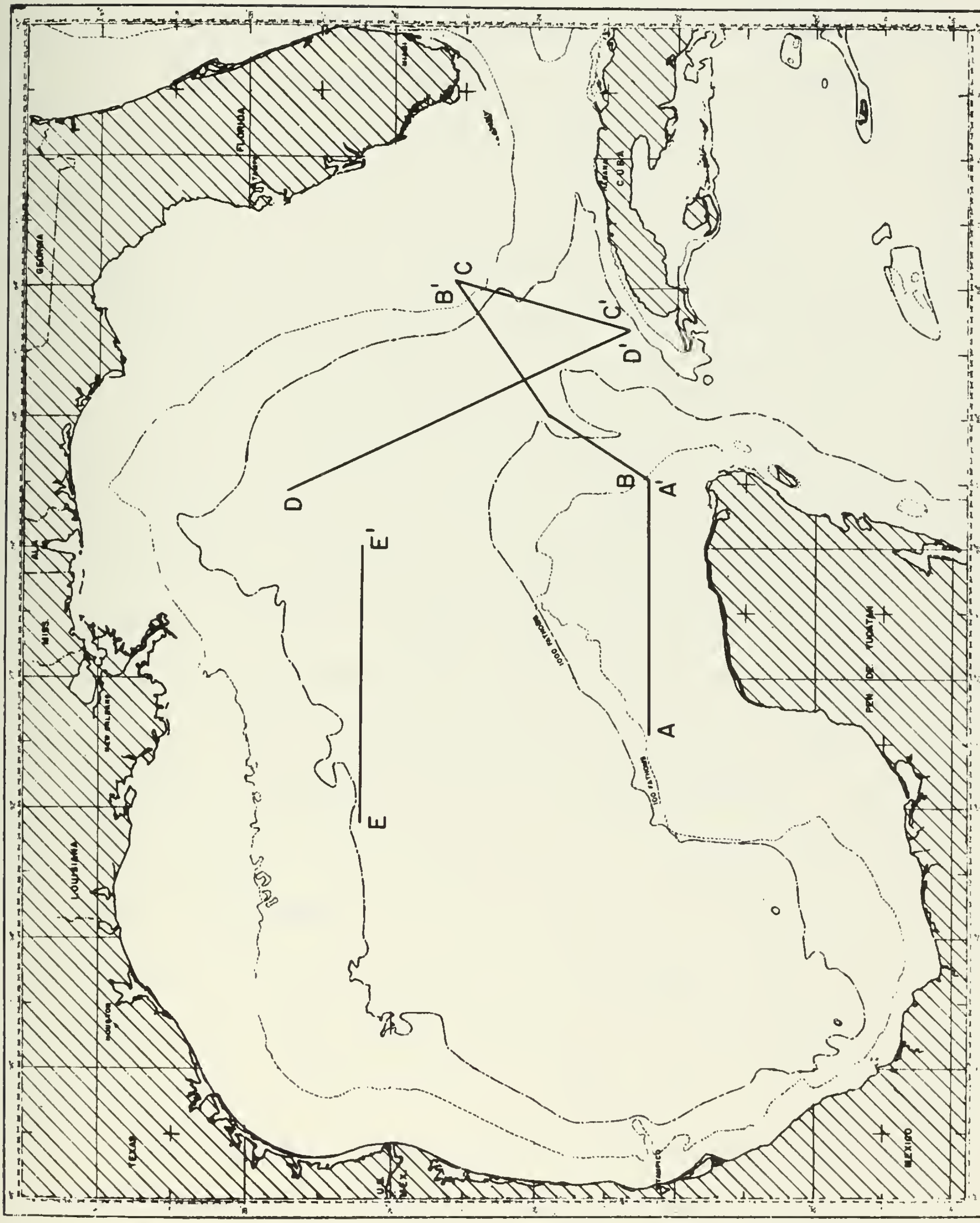

A
A'
B
B'
C
C'
D
D'
E
E'
FLORIDA
CUBA
GEORGIA
LOUISIANA
TEXAS
MEXICO
PEN DE YUCATAN
1000 FATHOMS
100 FATHOMS

FIGURE 8

distributions in the vertical sections is predicated on the assumption that such currents are geostrophic and are relative to an assumed level of no motion at some greater depth. Briefly, the direction of such currents relative to two areas of different temperature (density) is such that with warmer, less dense water on the right, the flow is directed into the vertical section.

Figures 9, 10, and 11, depicting the transect A-A' across the Campeche Bank (see also Fig. 1), reveal two interesting phenomena. At St. 22, about 50 n.m. (93 km.) west of the eastern edge of the Campeche Bank, an uplifting of relatively cooler water is evidenced which can rationally be attributed to the presence of the inflowing Yucatan Current not over 75 n.m. (139 km.) to the east. As the Yucatan Current approaches the narrow Yucatan Strait, the colder waters which have been traversing the Caribbean Basin at considerable depths (Wust, 1964:Plate XIX) are lifted into the shallower depths due to the restrictions imposed on the flow by the bathymetry. The prevailing winds (easterly) also tend to pile up the surface waters at the entrance to the channel. As the sill depth of the Yucatan Strait is estimated at about 1600 meters (Sverdrup et. al., 1942), the piling up effect of the colder, deeper waters at the sill results in some spillover into the Yucatan Strait. Additionally, the superposition of the swiftly flowing Yucatan Current aids in moving this colder water northward along the Strait, with the result that cold, low-salinity waters are lifted up the slopes of the Yucatan Strait. (See Figures 12, 13, and 14, Transect B-B', for the area just east of the

FIGURE 9. Temperature (degrees Celsius) along Transect A-A', 7-8 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 3708:1.

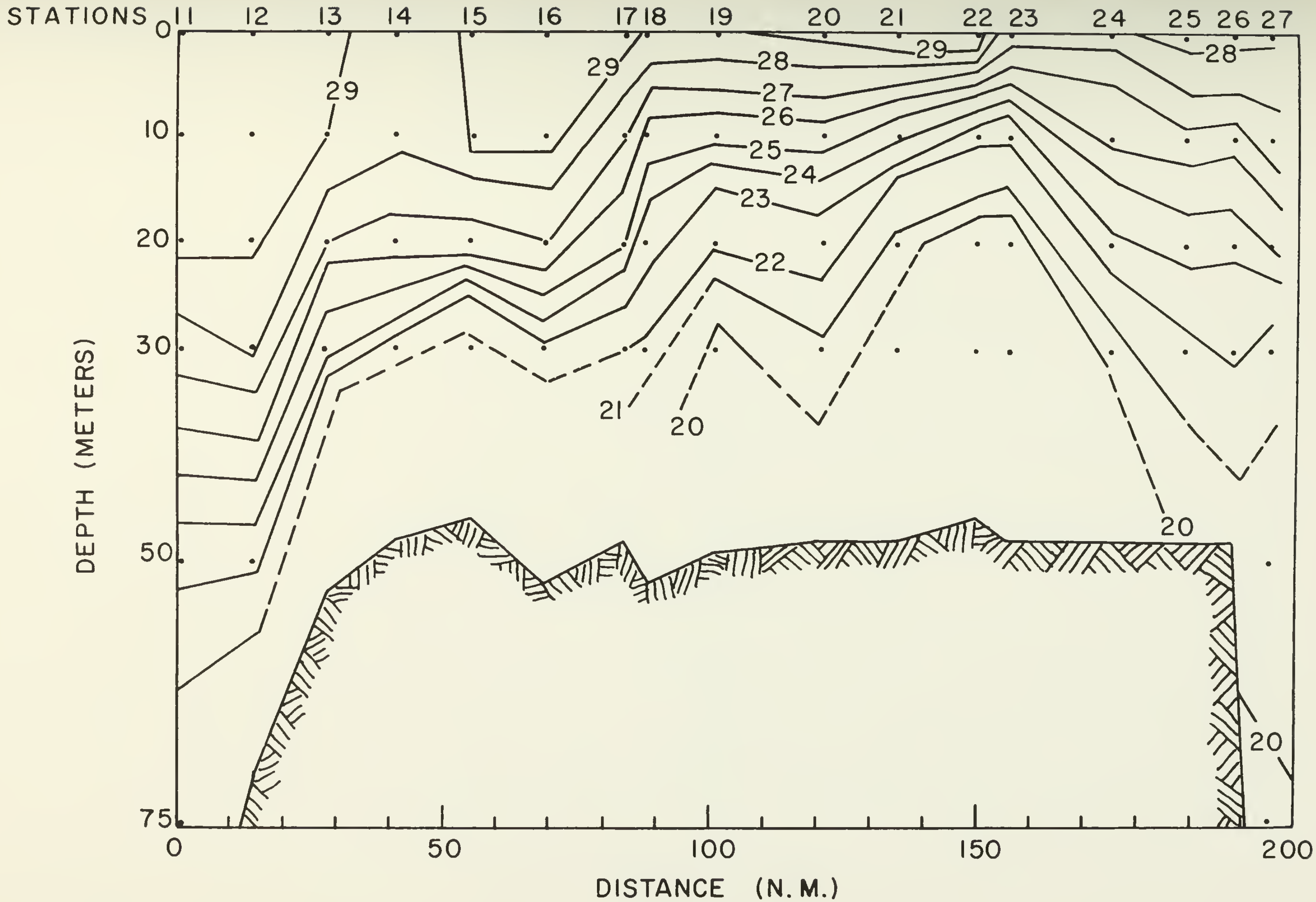

STATIONS
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
DEPTH (METERS)
0
10
20
30
50
75
DISTANCE (N. M.)
0
50
100
150
200
29
29
29
28
28
27
26
25
24
23
22
21
20
20
20

FIGURE 9

FIGURE 10. Salinity (parts per mille) along Transect A-A', 7-8 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 3708:1.

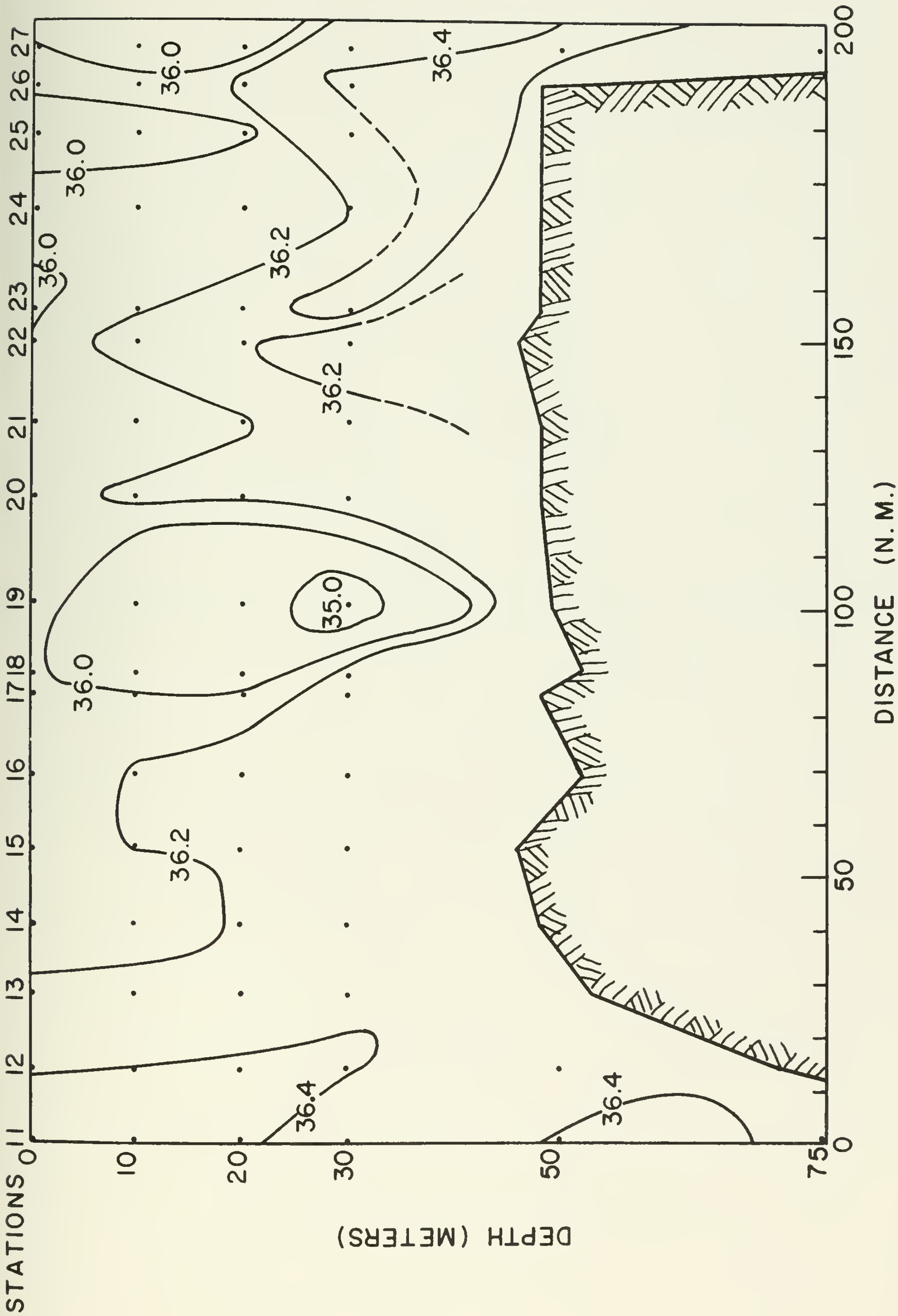
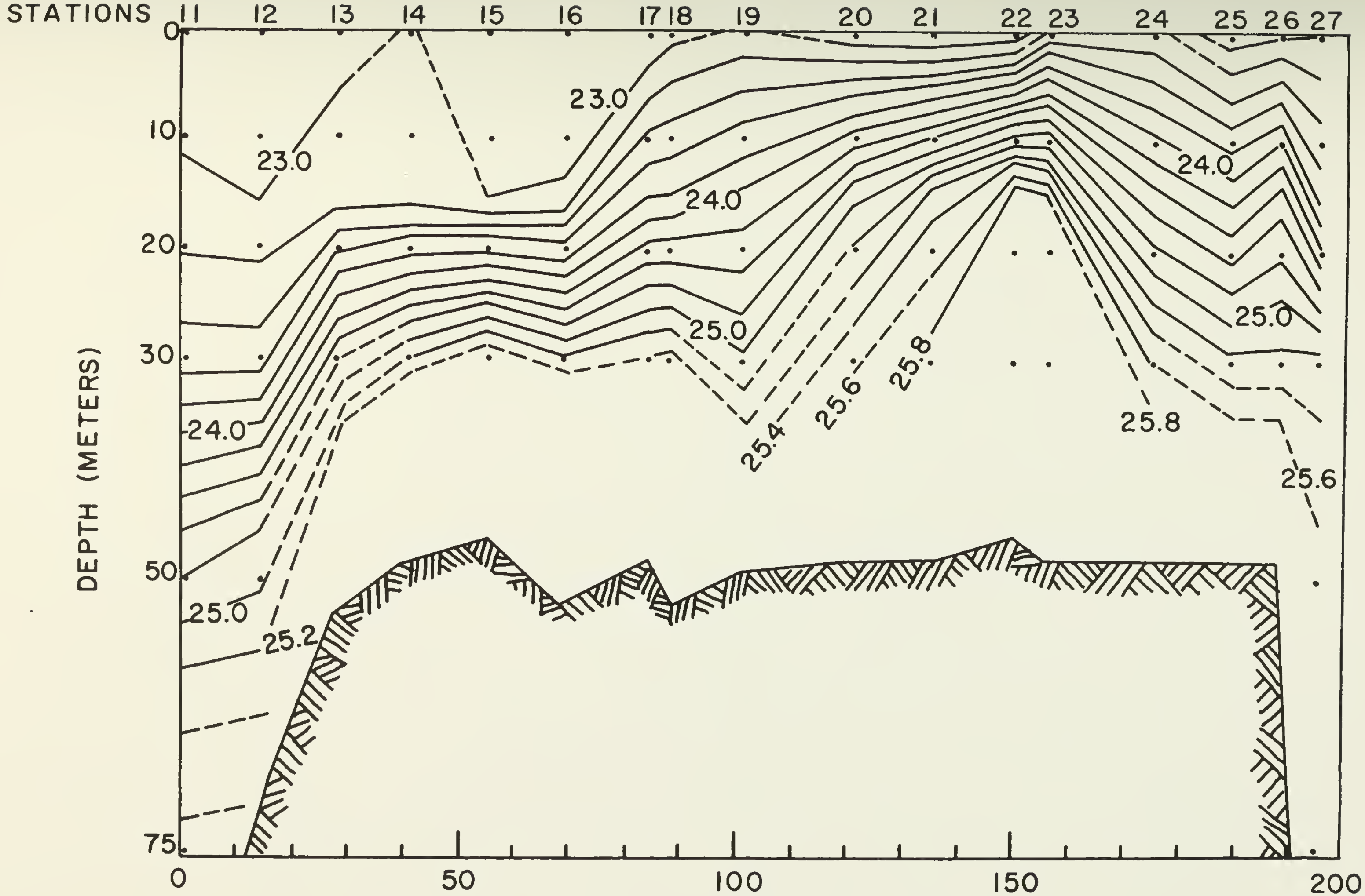

STATIONS
11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
DEPTH (METERS)
0
10
20
30
50
75
DISTANCE (N.M.)
0
50
100
150
200
36.0
36.2
36.4
35.0

FIGURE 10

FIGURE 11. Sigma-t along Transect A-A', 7-8 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 3708:1.



STATIONS
11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
DEPTH (METERS)
0
10
20
30
50
75
23.0
24.0
25.0
25.2
25.4
25.6
25.8
DISTANCE (N.M.)
0
50
100
150
200

FIGURE 11

FIGURE 12. Temperature (degrees Celsius) along Transect B-B', 8-9 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

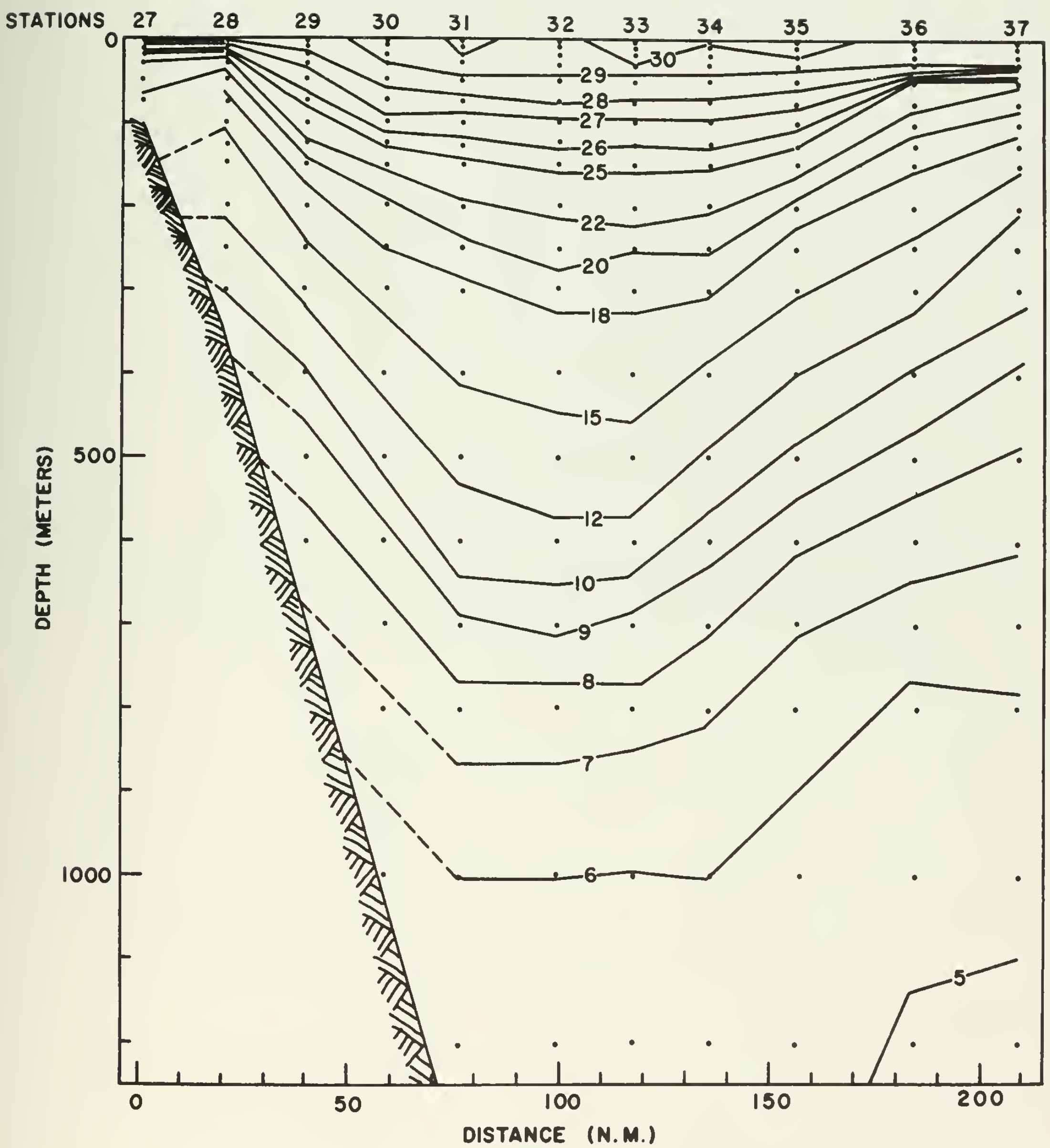

STATIONS
27
28
29
30
31
32
33
34
35
36
37
0
500
1000
DEPTH (METERS)
30
29
28
27
26
25
22
20
18
15
12
10
9
8
7
6
5
0
50
100
150
200
DISTANCE (N.M.)

FIGURE 12

FIGURE 13. Salinity (parts per mille) along Transect B-B', 8-9 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

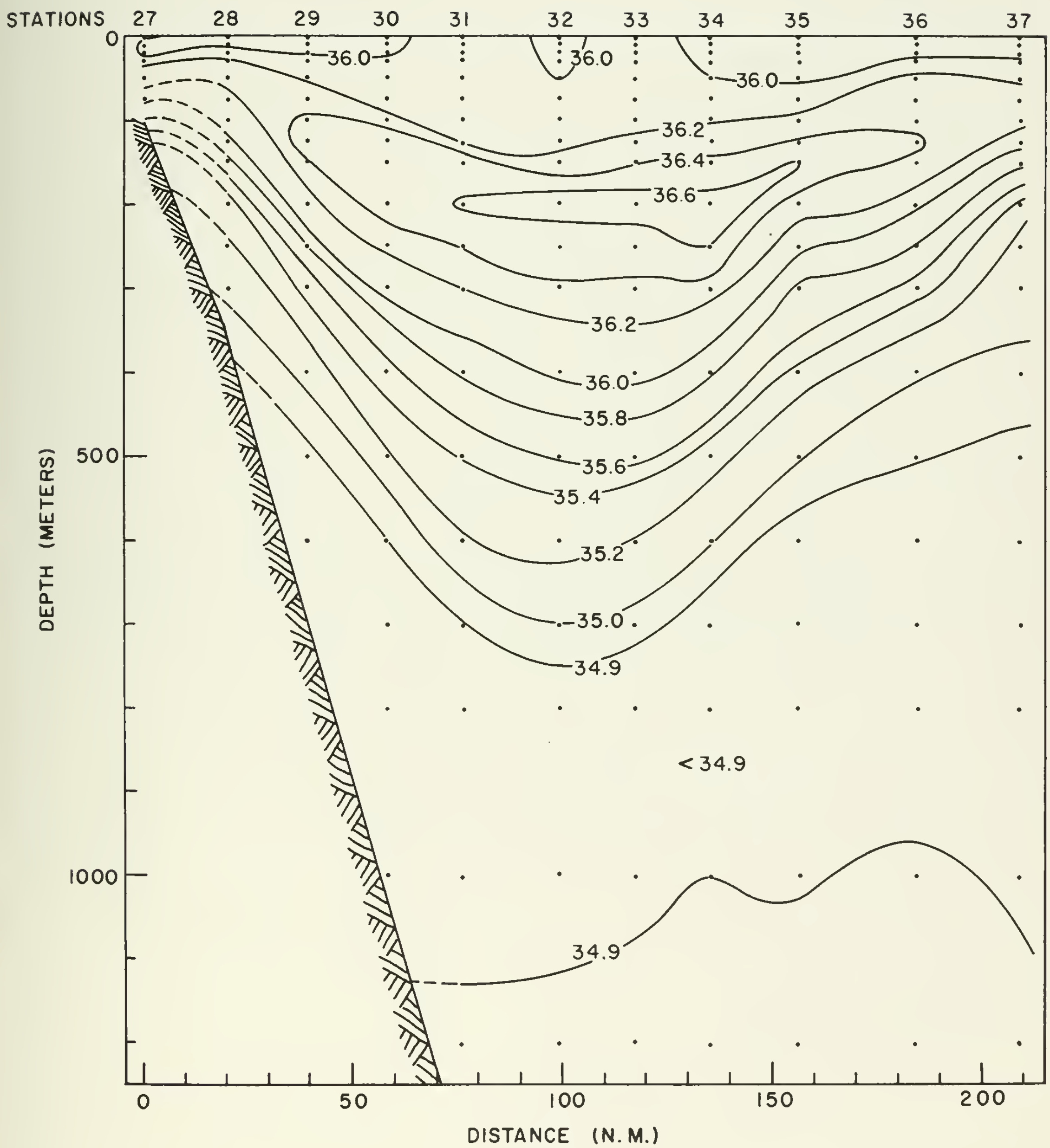

STATIONS
27
28
29
30
31
32
33
34
35
36
37
0
500
1000
DEPTH (METERS)
36.0
36.0
36.0
36.2
36.4
36.6
36.2
36.0
35.8
35.6
35.4
35.2
35.0
34.9
<34.9
34.9
0
50
100
150
200
DISTANCE (N.M.)

FIGURE 13

FIGURE 14. Sigma-t along Transect B-B', 8-9 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

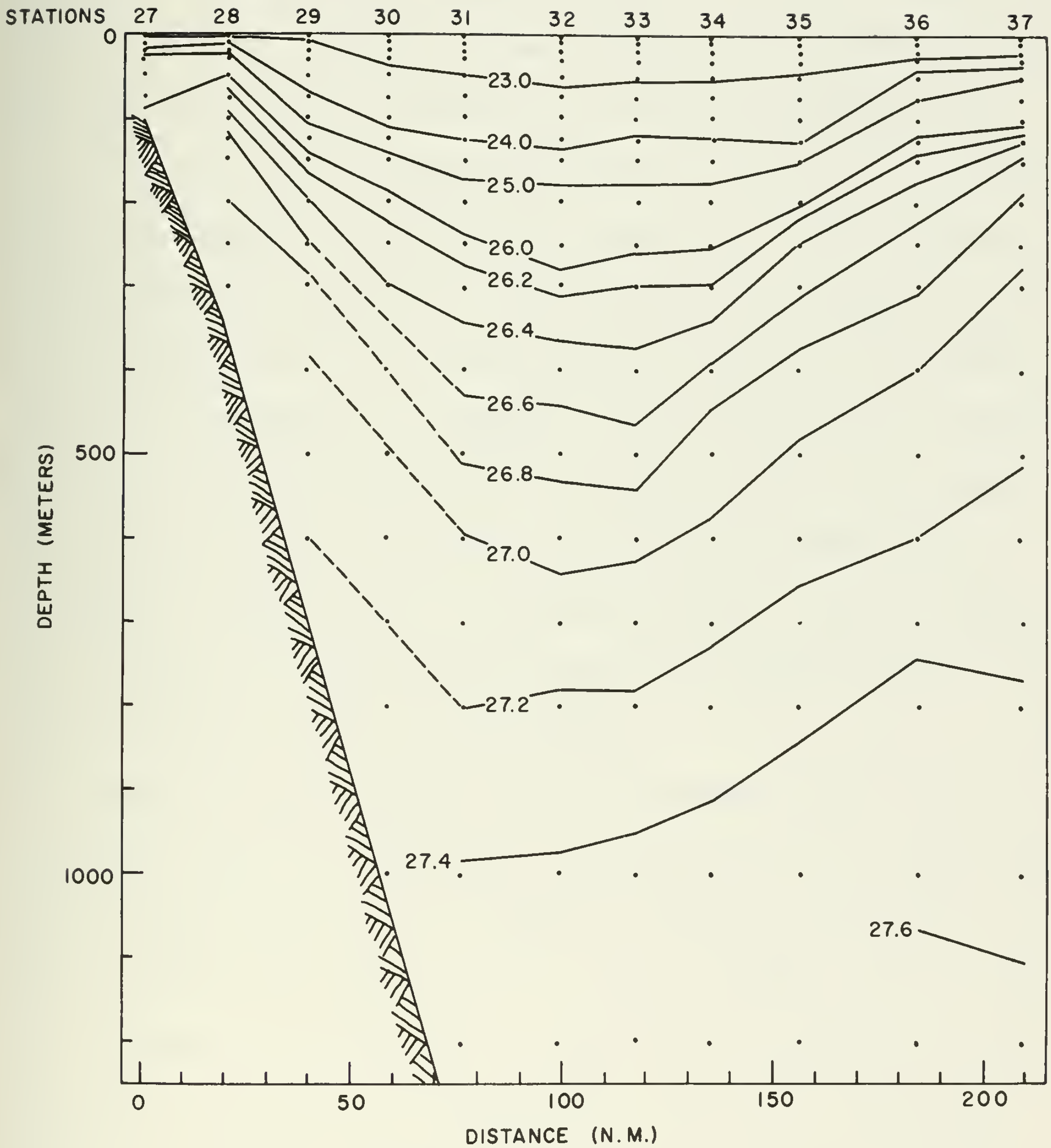

STATIONS
27
28
29
30
31
32
33
34
35
36
37
0
500
1000
DEPTH (METERS)
23.0
24.0
25.0
26.0
26.2
26.4
26.6
26.8
27.0
27.2
27.4
27.6
0
50
100
150
200
DISTANCE (N.M.)

FIGURE 14

Campeche Bank.) Some portions of this water eventually gain the precipice of the slope and spread horizontally over the bottom of the Campeche Bank, as they are no longer restricted to vertical uplift. Thus, at St. 22 there is evidence of the process described above.

At St. 14, where a surface temperature of 28.6° C. was recorded, there is a suggestion of upwelling, though weak. While Cochrane (1966) reported the presence of upwelling over the Campeche Bank for several summer cruises, and particularly in May 1965, and further states that upwelling "... probably is active from March through August," the vertical sections over the Campeche Bank for this August cruise do not show such upwelling. It is noted, however, that Cochrane's transects cross the 100-fathom curve at several locations north of A-A' and are therefore closer to the Yucatan Current as it bends northwestward around that isobath.

Transect B-B', extending across the Yucatan Strait and thence to the Florida Shelf depicts (Figures 12, 13, and 14) the northern semicircle of the Cuban Loop. The center of the loop, especially in the greater depths, is located at St. 32, with some skew toward the right (to the east) of the highest velocities (as indicated by the isoline gradients) as the surface is approached. The core of salinities higher than 36.6°/oo centered about St. 33, at a nominal depth of about 210 meters, is an excellent representation of Right-Hand waters; these Right-Hand waters are present in this loop out to the extent of the cell of salinities greater than 36.4°/oo, beyond which the waters are representative of Left-Hand water. Notice that the slopes of the

isolines in the eastern portion of this transect (the southeastward flowing Right-Hand Eastern Gulf Loop waters) are practically the same as those for the northward flowing Right-Hand water in the western portion. More significant, however, is the parallelism of the isolines to the bottom of the section (1200 meters), indicating that the inflowing and outflowing currents decrease uniformly from the surface to the depths represented. Surface currents based on dynamic computations relative to the 300-db surface -- above which depth the warm, high-salinity core of the Right-Hand waters is found -- might then be reliably used to give an indication of the flow beneath the 300-db surface. (Specific currents and transports found on this cruise are discussed in the following section.)

The "banded" structure of the Yucatan Current noted by Cochrane (1963, 1965, 1966) is not evident in this transect; however, it is possible that the current has united into a single flow (as depicted here) by the time it reaches this latitude (24° N.). The Yucatan Strait proper is some 100 n.m. (192 km.) upstream (to the south).

Figures 15, 16, and 17 show the isoline structures for the eastward flow out of the Gulf of Mexico (Transect C-C'). Notice that the patterns of isolines are practically the same as observed in the eastern section of transect B-B', indicating that there is very little modification of the outflowing waters in the short span between those two transects. The concentrated flow between Sts. 40 and 42, as evidenced by the sharp change in gradient of the isolines south of the latter station, is located at approximately 24° N., 84°

FIGURE 15. Temperature (degrees Celsius) along Transect C-C', 9-10 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

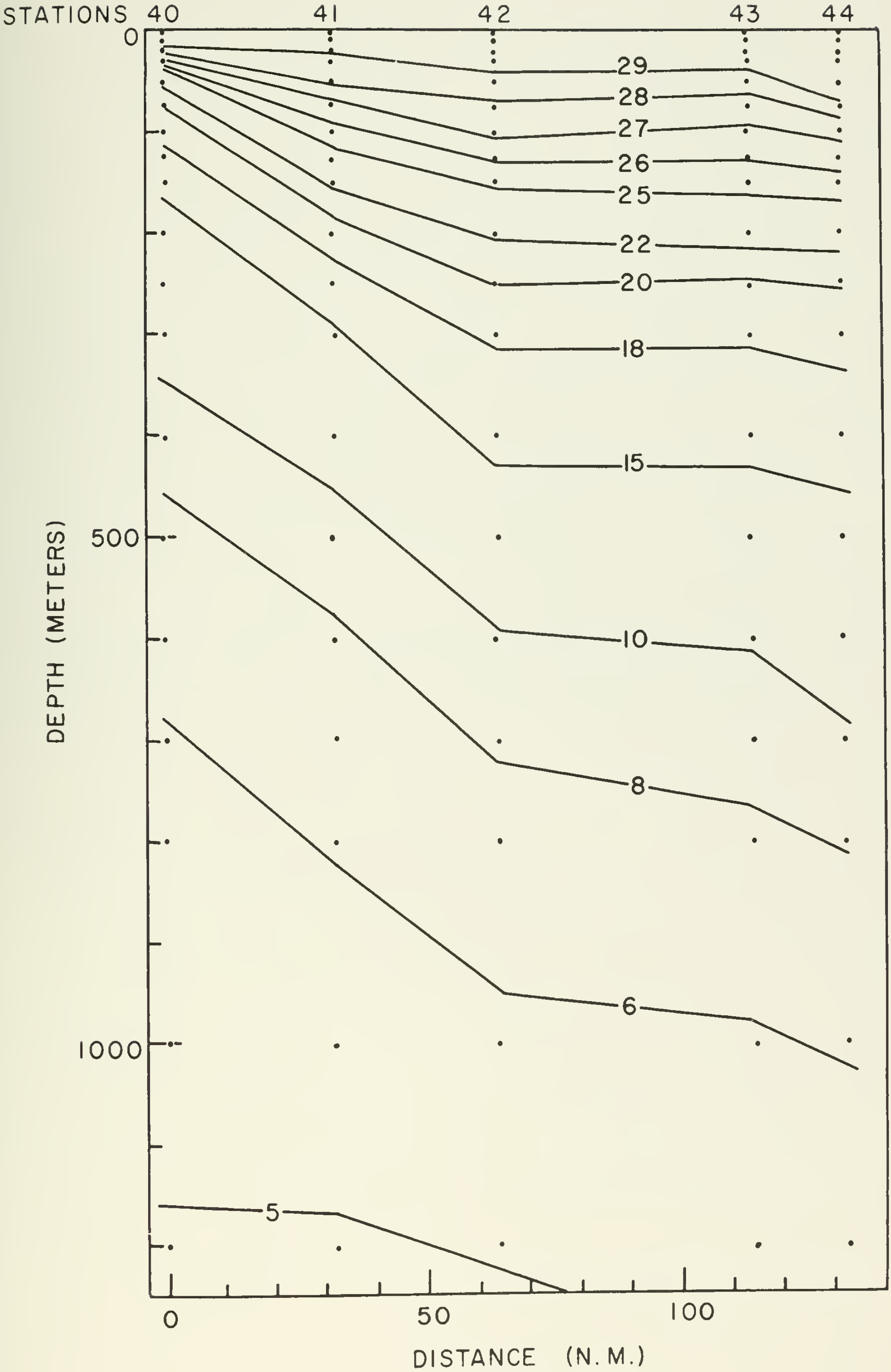

STATIONS 40
41
42
43
44
0
500
1000
DEPTH (METERS)
29
28
27
26
25
22
20
18
15
10
8
6
5
0
50
100
DISTANCE (N.M.)

FIGURE 15

FIGURE 16. Salinity (parts per mille) along Transect C-C', 9-10 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

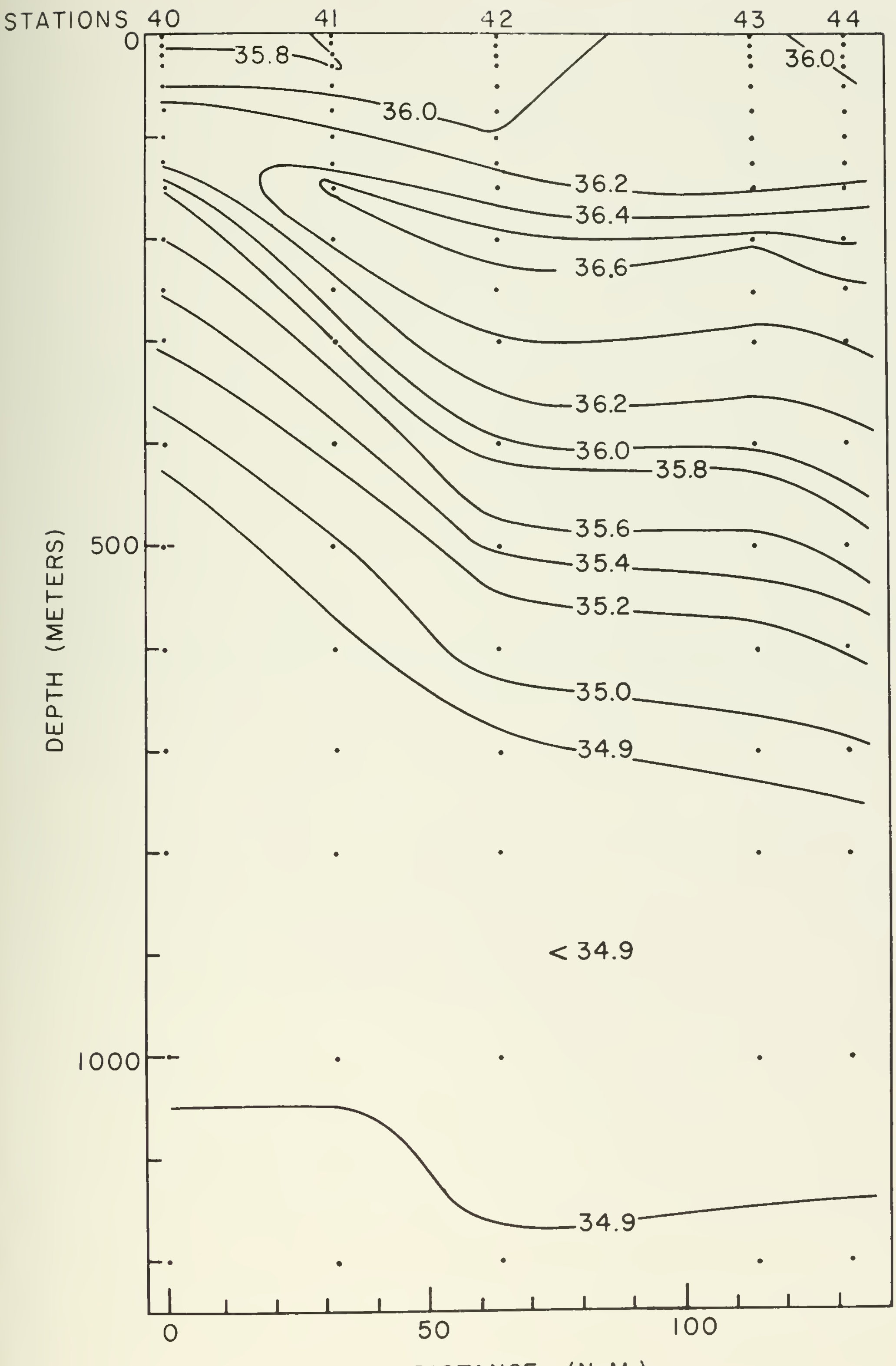

STATIONS 40
41
42
43
44
0
500
1000
DEPTH (METERS)
35.8
36.0
36.0
36.2
36.4
36.6
36.2
36.0
35.8
35.6
35.4
35.2
35.0
34.9
< 34.9
34.9
0
50
100
DISTANCE (N. M.)

FIGURE 16

FIGURE 17. Sigma-t along Transect C-C', 9-10 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

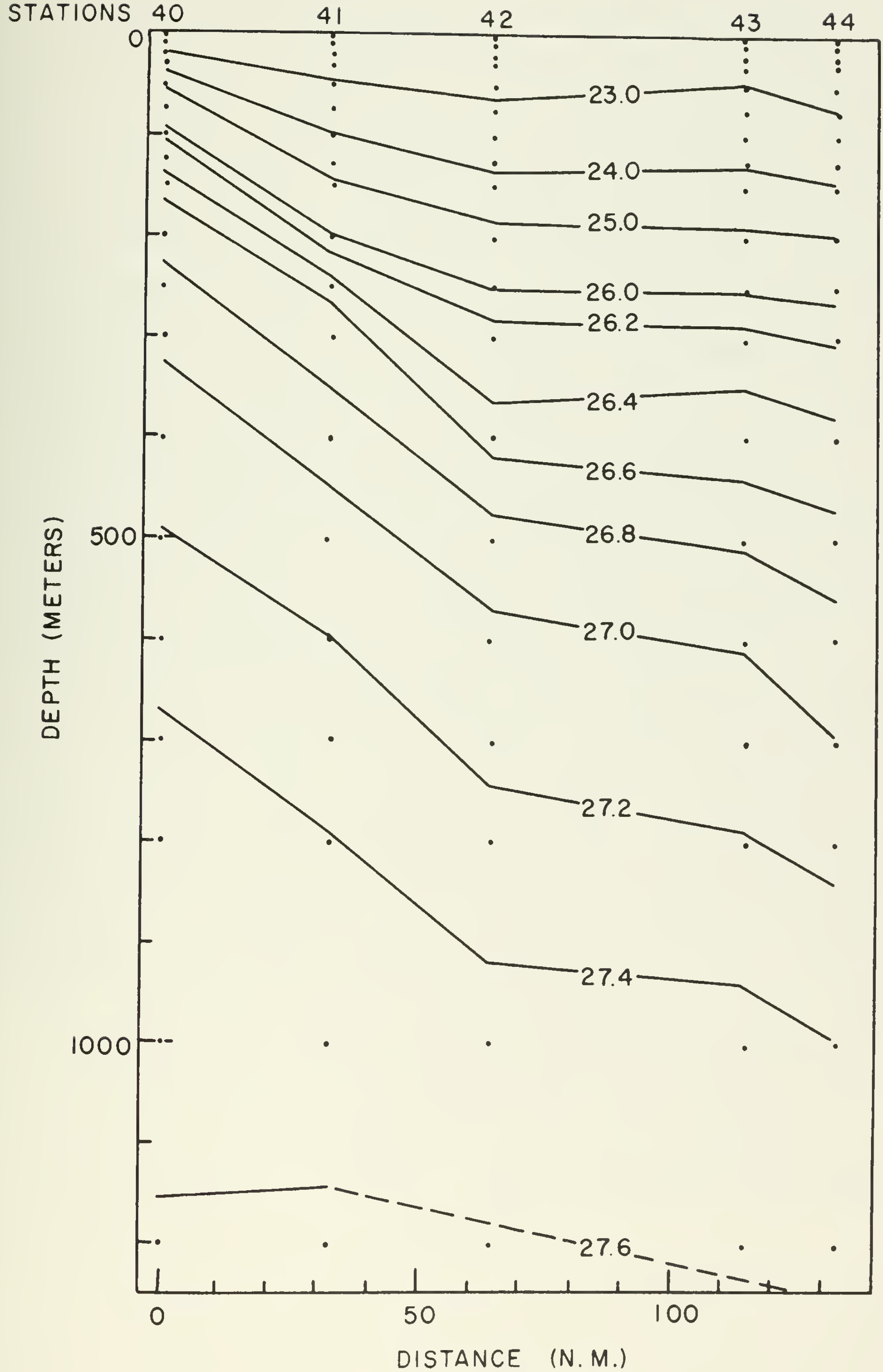

STATIONS 40
41
42
43
44
0
500
1000
DEPTH (METERS)
23.0
24.0
25.0
26.0
26.2
26.4
26.6
26.8
27.0
27.2
27.4
27.6
0
50
100
DISTANCE (N. M.)

FIGURE 17

W., and is coincident at that point with the 1000-fathom curve. The maximum velocity and transport through the eastern portion of transect B-B', upstream from this locale, and centered at about 24° 20' N., 84° 50' W. (near St. 35), is centrally located between the 1000-fathom curves off the Florida Shelf and Campeche Bank. This suggests that the streamlines of flow in the northeastern part of the Cuban Loop may have been governed at this time by the bathymetry.

Transect D-D' encompasses the longitudinal axis of the Cuban Loop, the combined exiting flows of both the Cuban Loop and the Northern Loop circulation present in the Eastern Gulf, and the flow of the eastern semi-circle of the Northern Loop, as well as a large, cold-water tongue extending well off from the Florida Shelf to a location between the Cuban and Northern Loops. Figures 18, 19, and 20 show the vertical sections of temperature, salinity, and sigma-t along this transect. (Figure 24 is also helpful in visually organizing the features of this transect.) The center of the Cuban Loop consists entirely of Right-Hand waters; there is almost no motion of these interior waters except for the indication of a slight eastward flow below 400 meters at the very southern end of the transect. The cold, low-salinity tongue of waters extending out from the Florida Shelf, near Sts. 51 and 52, separates the Northern Loop from the Cuban Loop and apparently prevents a direct southeastward flow of the Northern Loop toward the Florida Straits.

In this transect, as in the previous ones describing the Cuban Loop flow, the maximum slopes of the isolines are consistently parall-

FIGURE 18. Temperature (degrees Celsius) along Transect D-D', 10-12 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

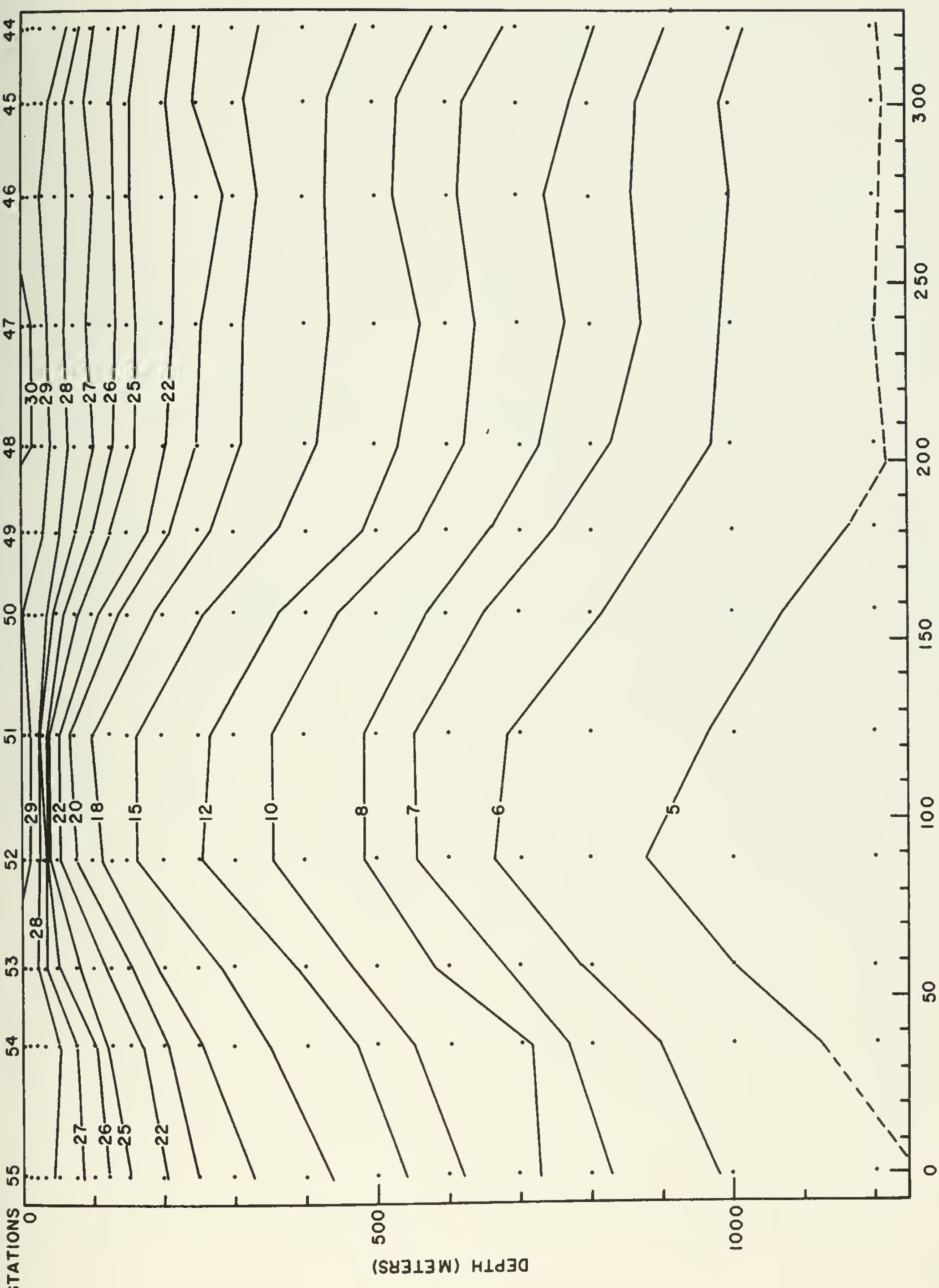

STATIONS
44
45
46
47
48
49
50
51
52
53
54
55
DEPTH (METERS)
0
500
1000
DISTANCE (N.M.)
0
50
100
150
200
250
300
30
29
28
27
26
25
22
20
18
15
12
10
8
7
6
5

FIGURE 18

FIGURE 19. Salinity (parts per mille) along Transect D-D', 10-12 August 1966, ALAMINOIS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

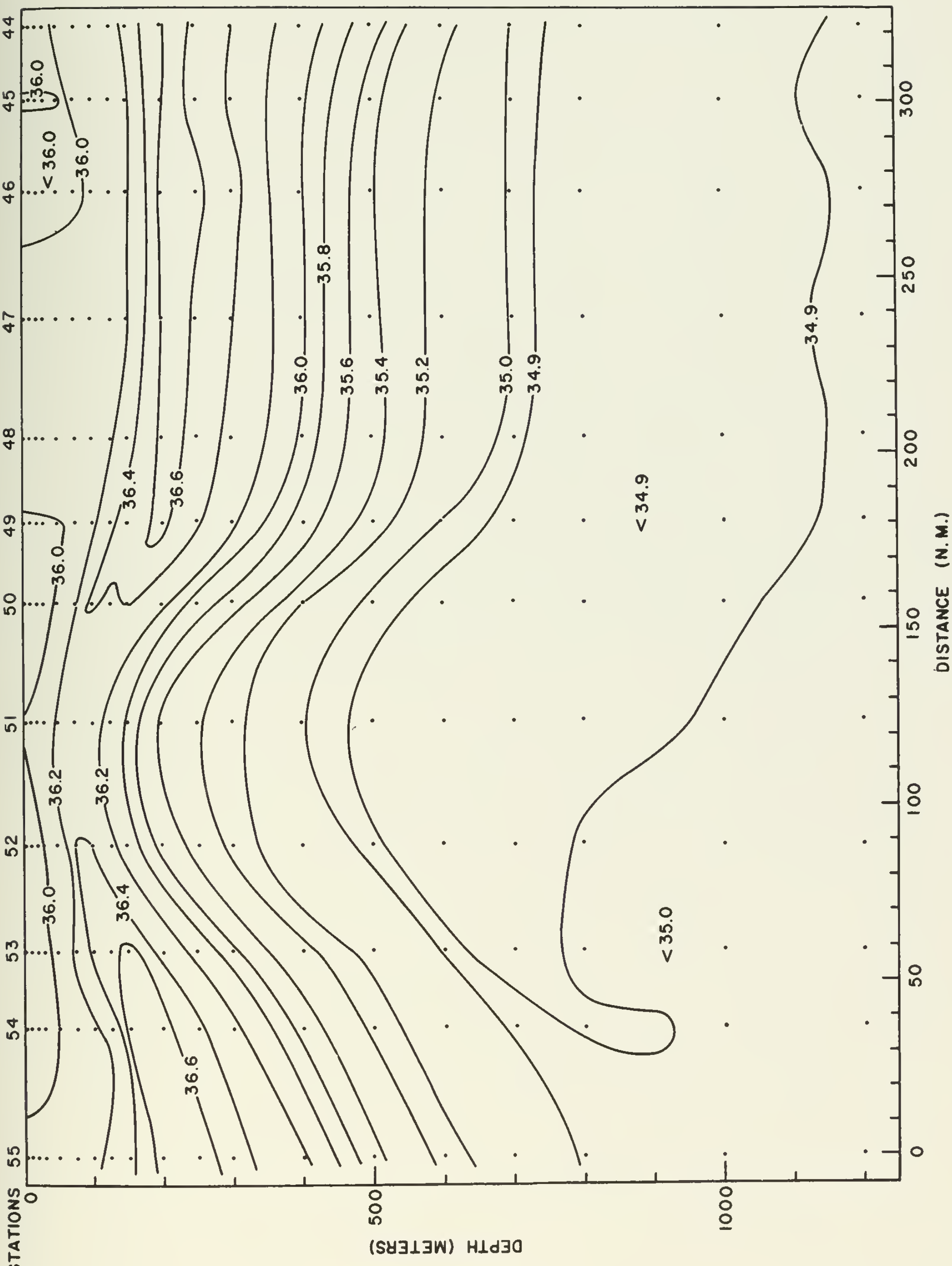

STATIONS
44
45
46
47
48
49
50
51
52
53
54
55
DEPTH (METERS)
0
500
1000
DISTANCE (N.M.)
0
50
100
150
200
250
300
36.0
< 36.0
36.2
36.4
36.6
35.8
35.6
35.4
35.2
35.0
34.9
< 34.9
< 35.0

FIGURE 19

FIGURE 20. Sigma-t along Transect D-D', 10-12 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

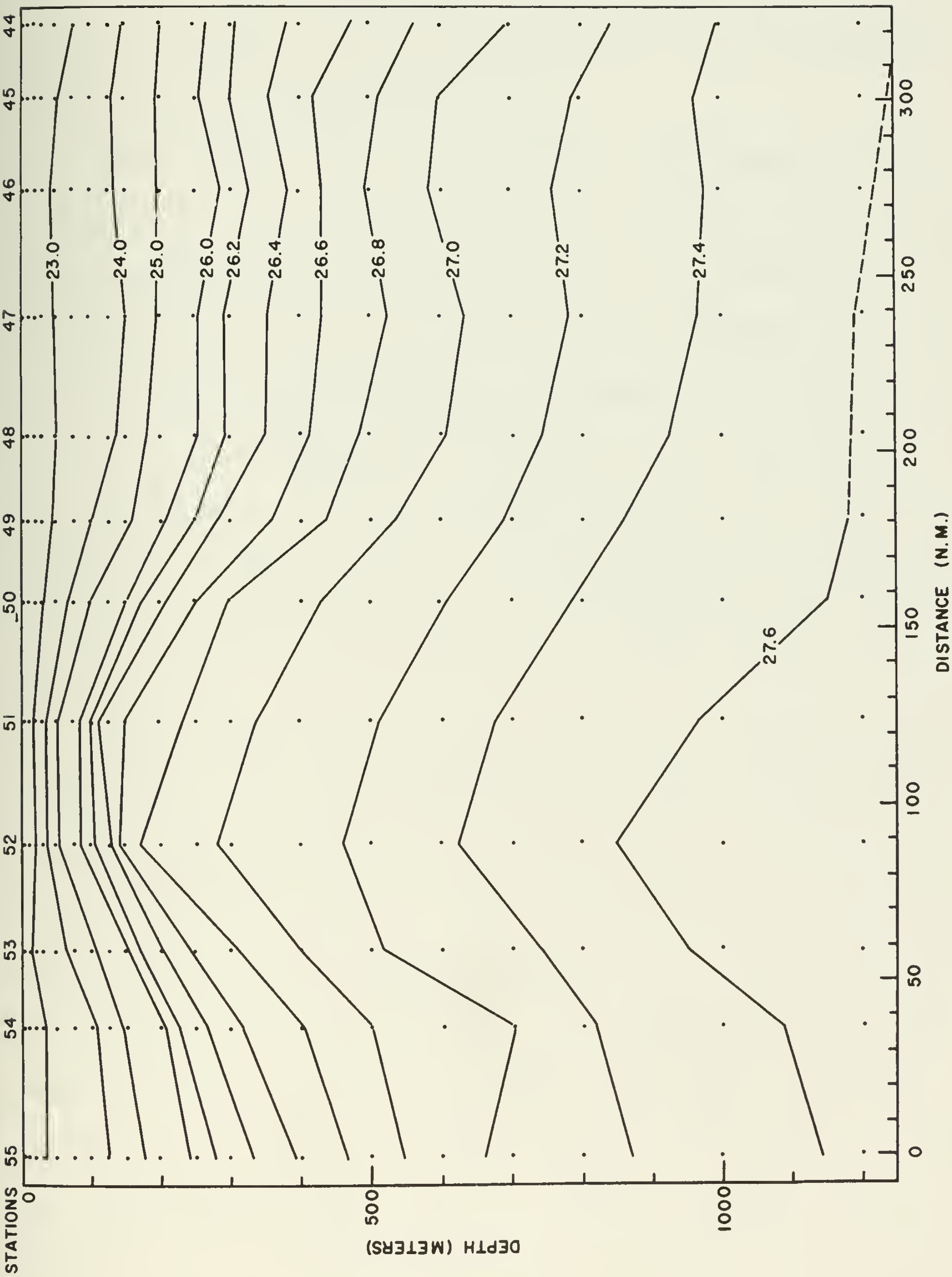

STATIONS
44
45
46
47
48
49
50
51
52
53
54
55
DEPTH (METERS)
0
500
1000
23.0
24.0
25.0
26.0
26.2
26.4
26.6
26.8
27.0
27.2
27.4
27.6
DISTANCE (N.M.)
0
50
100
150
200
250
300

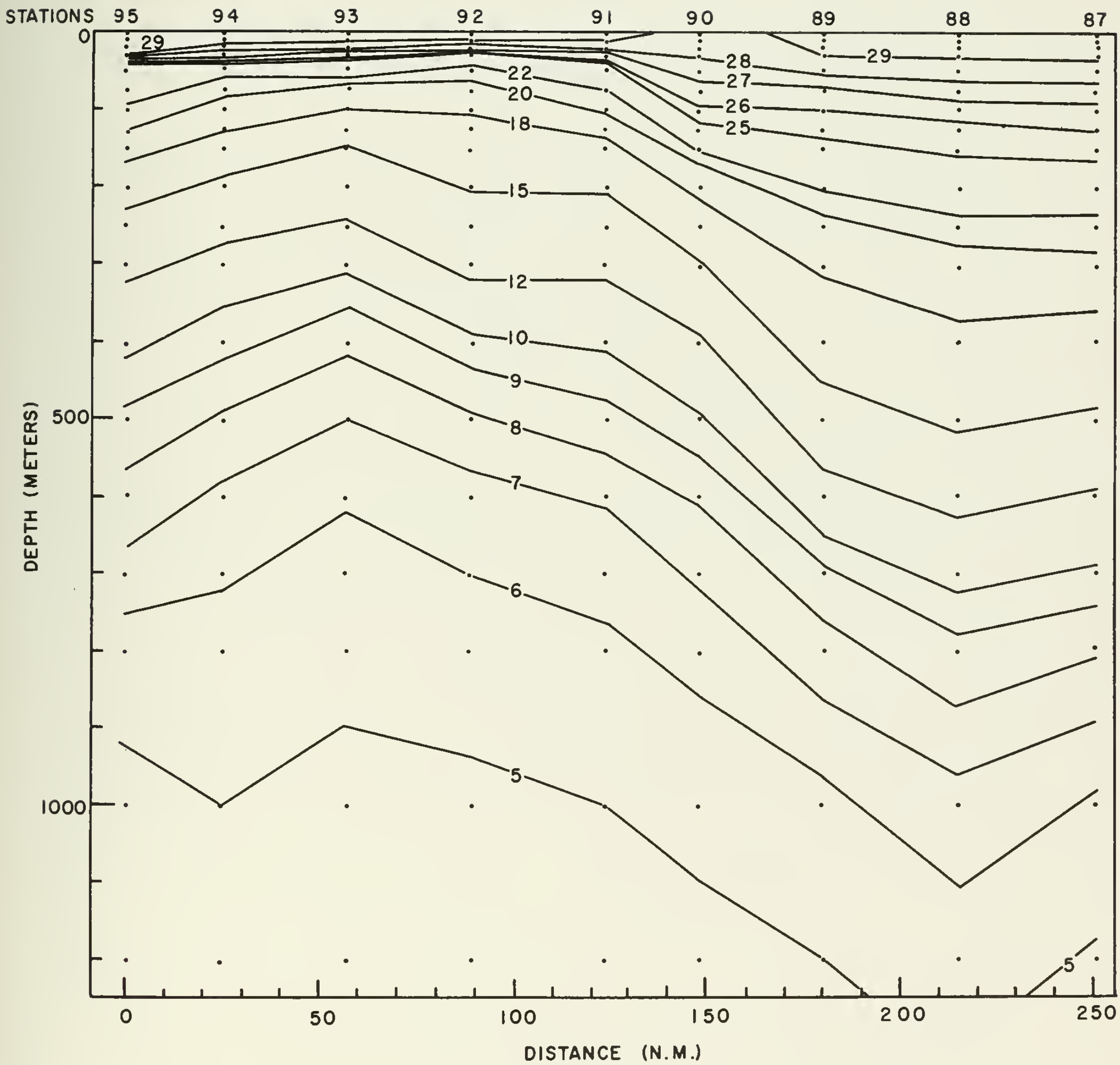
FIGURE 20

el down to the bottom of the sections. Of special significance, however, is that the gradients of the Northern Loop flow, in the northern portion of transect D-D', are approximately the same as depicted for all other transects of the Cuban Loop.

Figures 21, 22, and 23, depicting the cross-current profiles for transect E-E', across the western semi-circle of the Northern Loop flow, illustrate the same dynamic features of the preceding sections. The center of the anticyclonic Northern Loop circulation is located at St. 88, near 26° N., 88° 30' W., as evidenced by the apex of isolines at that station. The slopes of isolines in this transect are not quite as steep as in the previous transect across the Northern Loop flow (D-D'), suggesting that the flow is moderating and spreading westward during its travel around the southeastern quadrant of the Northern Loop.

The most significant feature of the vertical sections, taken collectively, is that the presence of the Right-Hand waters is consistently demonstrated by the core of warm, high-salinity water between 175-225 meters depth. Further, the waters of the Cuban Loop and the Northern Loop circulation patterns are in motion to at least 1200 meters (and probably deeper). The maximum velocities of the Eastern Gulf Loop Current, as depicted by the slopes of isolines in the vertical sections, lie not over the core of the Right-Hand waters but rather are found to the left of the core (facing in the direction of flow) over the maximum gradients of the isolines joining the Right-Hand and Left-Hand waters. There is representation of considerable

FIGURE 21. Temperature (degrees Celsius) along Transect E-E', 16-18 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.



STATIONS
95
94
93
92
91
90
89
88
87
0
500
1000
DEPTH (METERS)
29
28
27
26
25
22
20
18
15
12
10
9
8
7
6
5
29
5
0
50
100
150
200
250
DISTANCE (N.M.)

FIGURE 21

FIGURE 22. Salinity (parts per mille) along Transect E-E', 16-18 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

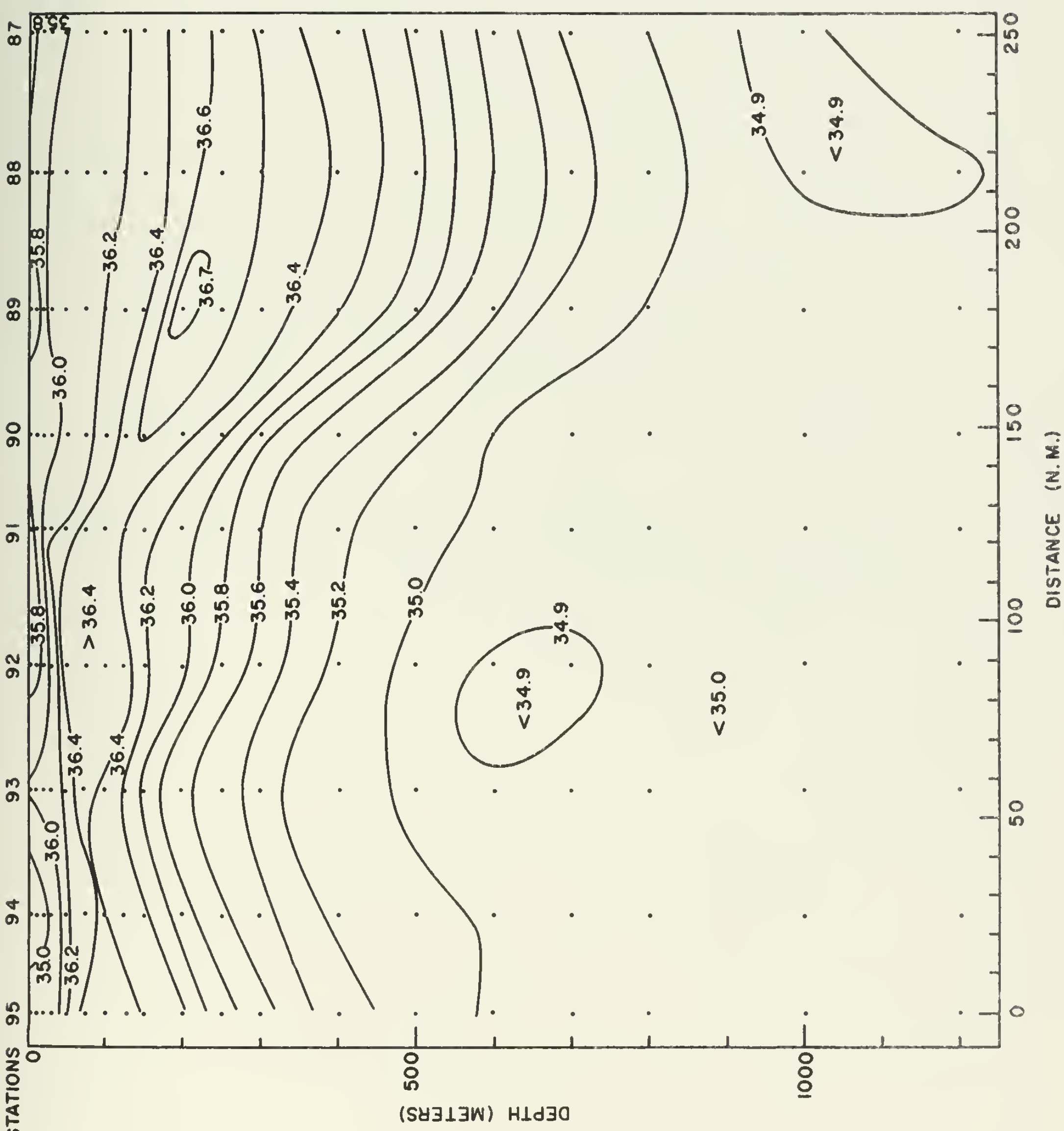

STATIONS
87
88
89
90
91
92
93
94
95
DEPTH (METERS)
0
500
1000
DISTANCE (N.M.)
0
50
100
150
200
250
35.8
36.2
36.4
36.6
36.7
36.0
>36.4
35.6
35.4
35.2
35.0
34.9
<34.9
<35.0

FIGURE 22

FIGURE 23. Sigma-t along Transect E-E', 16-18 August 1966, ALAMINOS 66-A-11. Dots represent standard depth sampling levels. Vertical exaggeration 371:1.

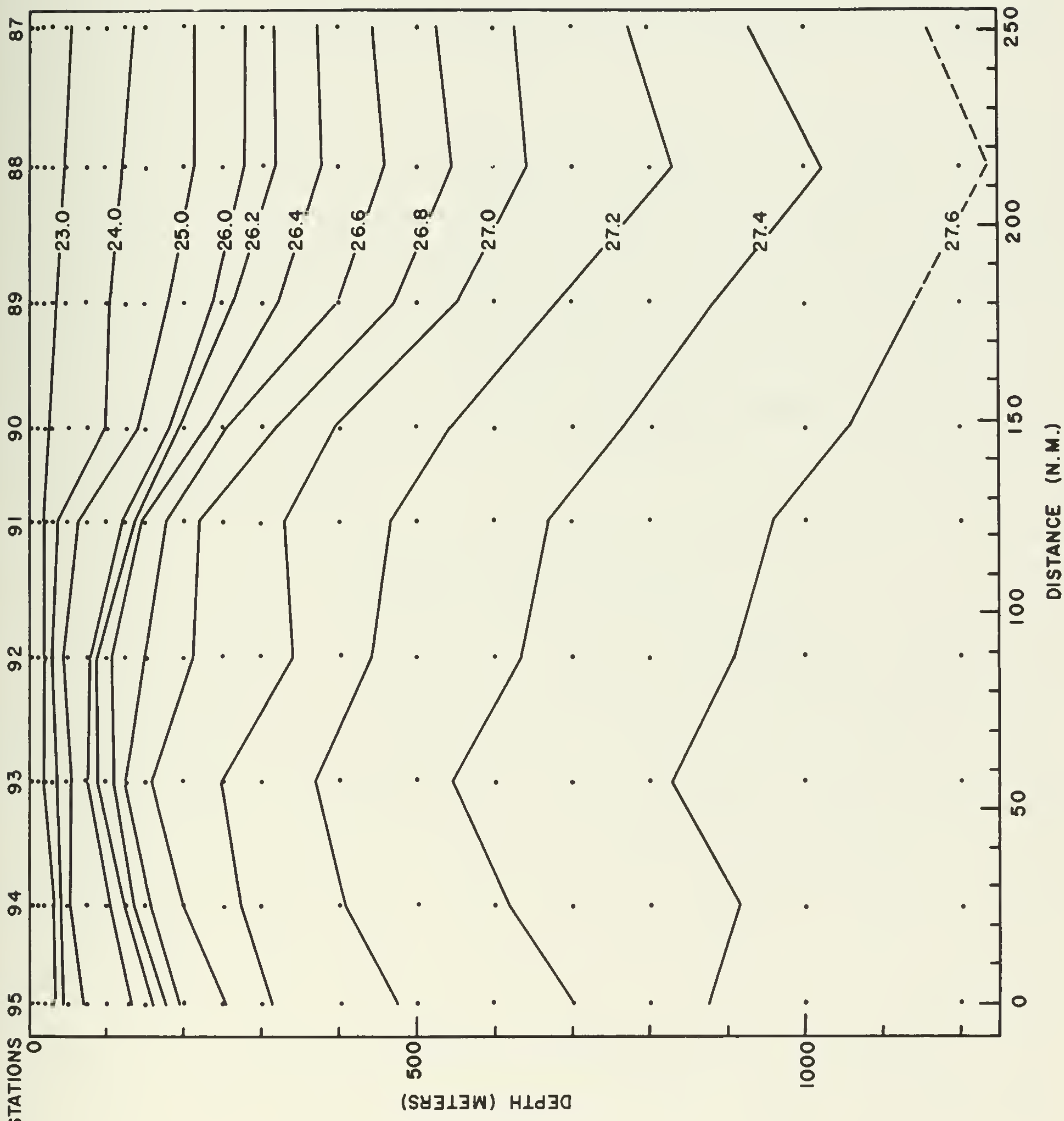

STATIONS
87
88
89
90
91
92
93
94
95
0
500
1000
DEPTH (METERS)
23.0
24.0
25.0
26.0
26.2
26.4
26.6
26.8
27.0
27.2
27.4
27.6
0
50
100
150
200
250
DISTANCE (N.M.)

FIGURE 23

uplift of the colder, less-saline waters toward the edges of the flow. Finally, the flows within the Northern Loop and the Cuban Loop are practically equal in magnitude, suggesting that they are but a single system in relation to the surrounding waters of the Eastern Gulf of Mexico.

Vertical profiles of temperature, salinity, and sigma-t for all other legs of ALAMINOS 66-A-11 were prepared for study; these other sections exhibited the same phenomena as presented in this discussion and have not been reproduced for this paper. They are, however, being retained in the Department of Oceanography files for their historical reference value.

E. Currents and Transports

The description of relative current velocities and volume transports of waters in the Eastern Gulf is based on the assumption that there are no accelerations other than those due to the pressure gradient and the Coriolis force and that these two accelerations are in balance (geostrophic flow). The 1000-db surface was selected as the reference level of no relative motion; as a result of this decision, an error of 10 cm/sec in the geostrophic current velocities in the upper water layers may be considered possible (Nowlin and McLellan, 1967). Choice of a deeper reference level (<u>i.e.</u>, 1200-db) was considered but rejected because a large number of stations within the Eastern Gulf circulation pattern would not have been incorporated.

Several stations are located in such proximity to the bordering

continental shelf regions (e.g., Sts. 28, 37, 40, 74, and 60; see Fig. 1) that at these locations the geostrophic flow assumption is probably invalid (due to frictional forces from current shear); this must be considered when viewing the resulting computations for these areas.

Figure 24 depicts the geopotential (dynamic height) anomalies as contoured from the August 1966 data for evaluation of the direction and magnitude of surface currents relative to the 1000-db surface. Figure 25 depicts the dynamic height anomalies for the surface relative to the 300-db reference level. Note the similarity in the general circulation patterns. Dynamic computations to the 300-db surface, while subject to certain misrepresentation of the overall circulation, were used for comparative analysis of the surface velocities and volume transports for the upper 300 meter layer to the dominant flow for the water column from the surface to 1000 meters.

Figures 27 through 30, profiles of the sea surface based on dynamic computations (to the 1000-db surface), reflect the property distributions depicted in the vertical sections previously discussed and for other cruise legs not incorporated in cross-current transects.

The dominant Eastern Gulf Loop circulation features (Figs. 24 and 25) are the heart-shaped, nearly closed, anticyclonic Northern Loop centered near St. 88 and the tongue-like Cuban Loop. The most interesting phenomena is the "neutral point of first order (hyperbolic point) flow" (Sverdrup et. al., 1942) centered near 24° 45' N., 87° W.; this area is referred to hereafter as the "neck" between the

FIGURE 24. Dynamic topography of the surface relative to the 1000-db surface, ALAMINOS 66-A-11, 4-18 August 1966. Contour interval, 0.1 dynamic meters. Dots represent STD station locations. See Figure 1 for identification of stations.

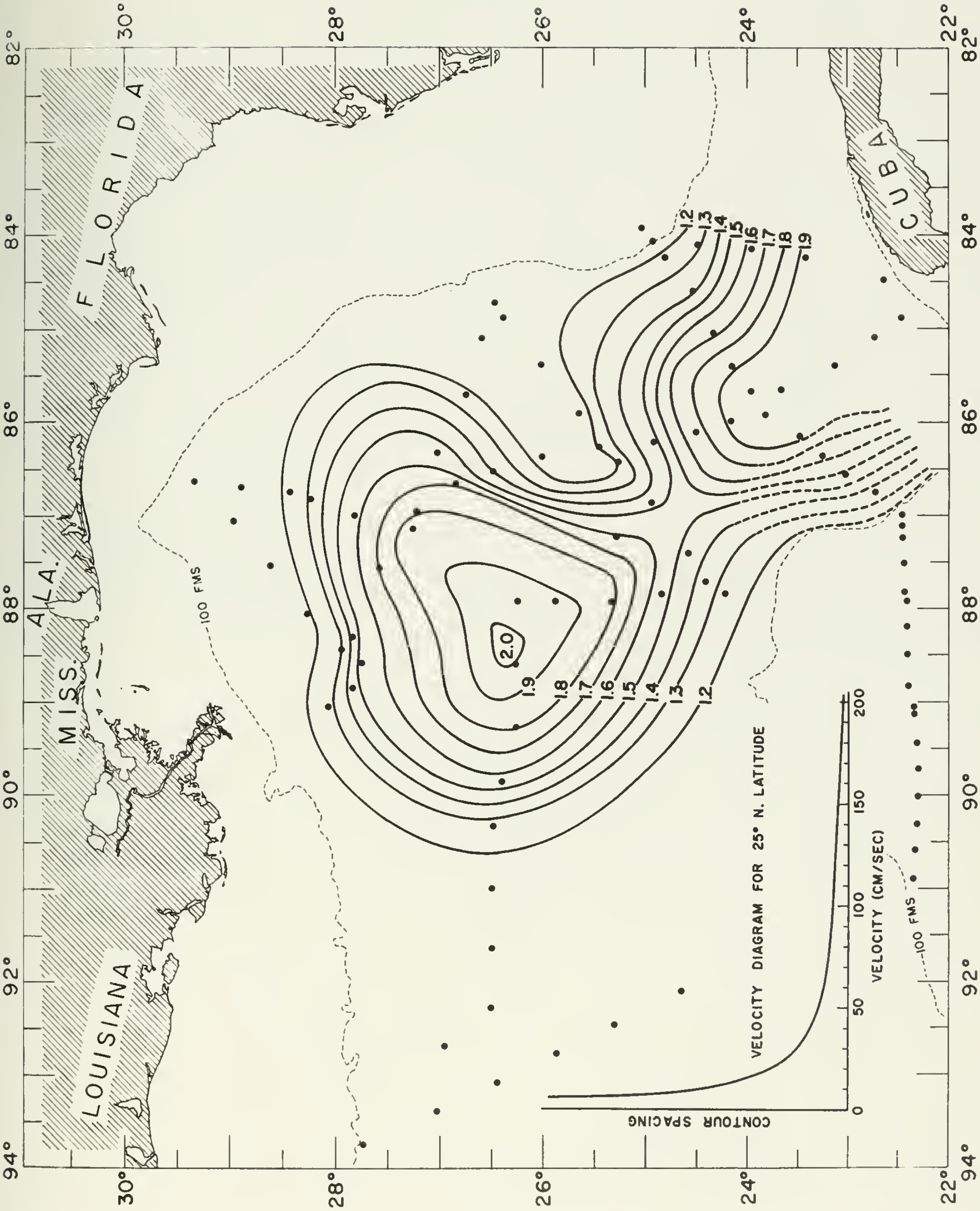

FLORIDA
ALA.
MISS.
LOUISIANA
CUBA
100 FMS
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
VELOCITY DIAGRAM FOR 25° N. LATITUDE
CONTOUR SPACING
VELOCITY (CM/SEC)
0
50
100
150
200
30°
28°
26°
24°
22°
82°
84°
86°
88°
90°
92°
94°

FIGURE 24

FIGURE 25. Dynamic topography of the surface relative to the 300-db surface, ALAMINOS 66-A-11, 4-18 August 1966. Contour interval, 0.1 dynamic meters. Dots represent STD station locations. See Figure 1 for identification of stations.

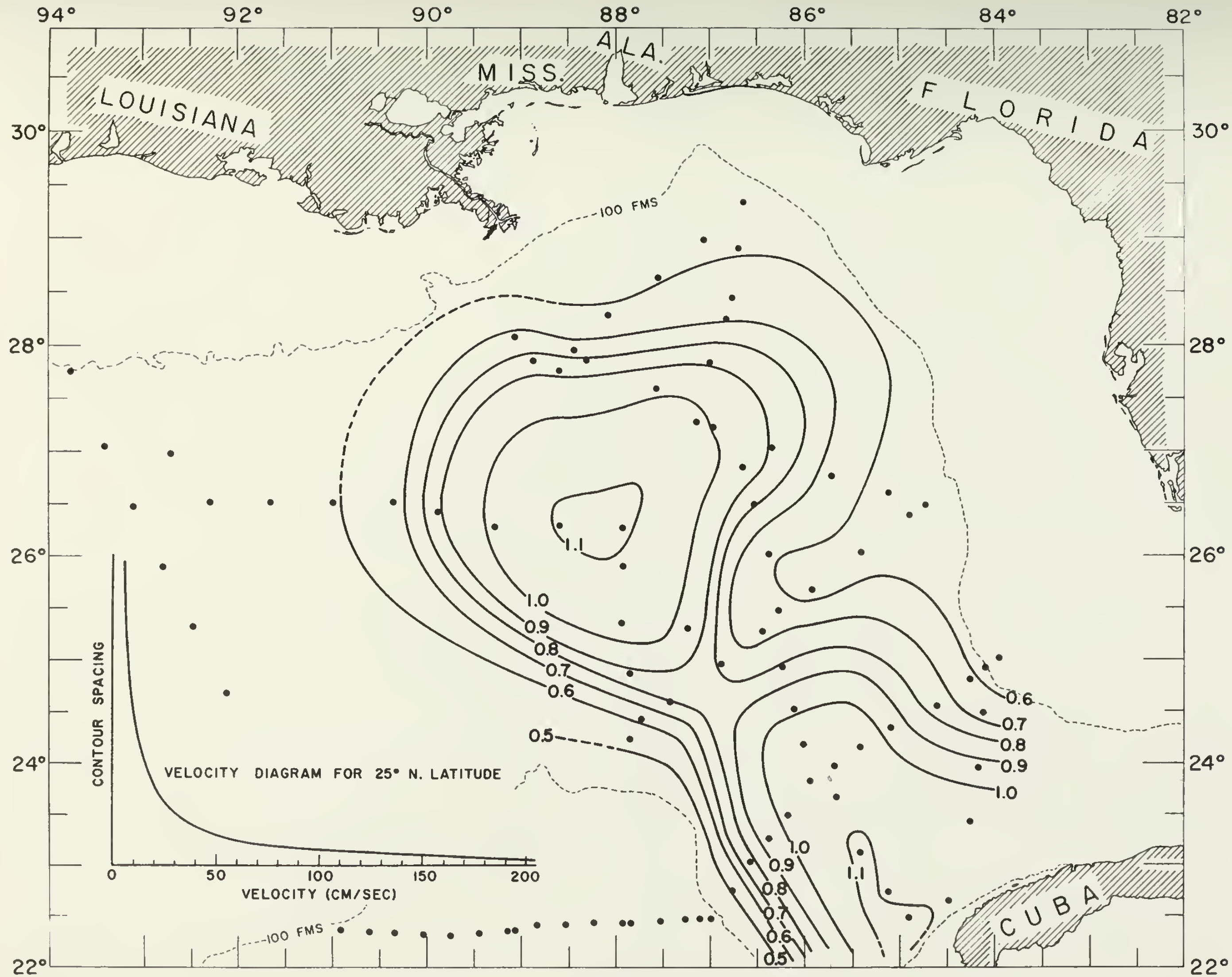
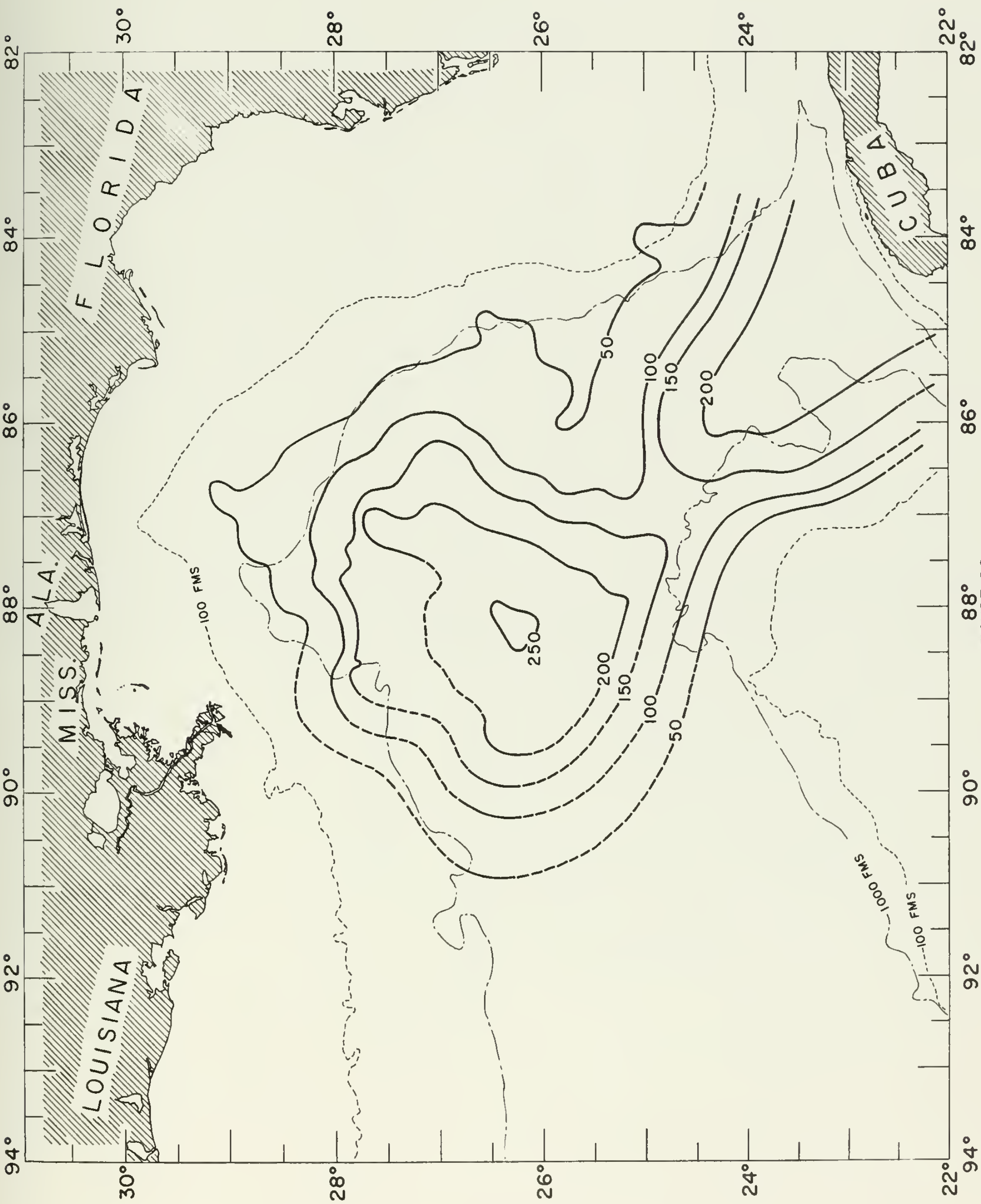

ALA.
MISS.
LOUISIANA
FLORIDA
CUBA
100 FMS
VELOCITY DIAGRAM FOR 25° N. LATITUDE
CONTOUR SPACING
VELOCITY (CM/SEC)
0
50
100
150
200
1.1
1.0
0.9
0.8
0.7
0.6
0.5
94°
92°
90°
88°
86°
84°
82°
30°
28°
26°
24°
22°

FIGURE 25

FIGURE 26. Topography of the 22° C. isothermal surface. Contour interval 50 meters.



FLORIDA
ALA.
MISS.
LOUISIANA
CUBA
100 FMS
1000 FMS
100 FMS
50
100
150
200
250
200
150
100
50
30°
28°
26°
24°
22°
82°
84°
86°
88°
90°
92°
94°

FIGURE 26

FIGURE 27. Profiles of the sea surface from dynamic computations, Stations 31-51, 8-11 August 1966, ALAMINOS 66-A-11.

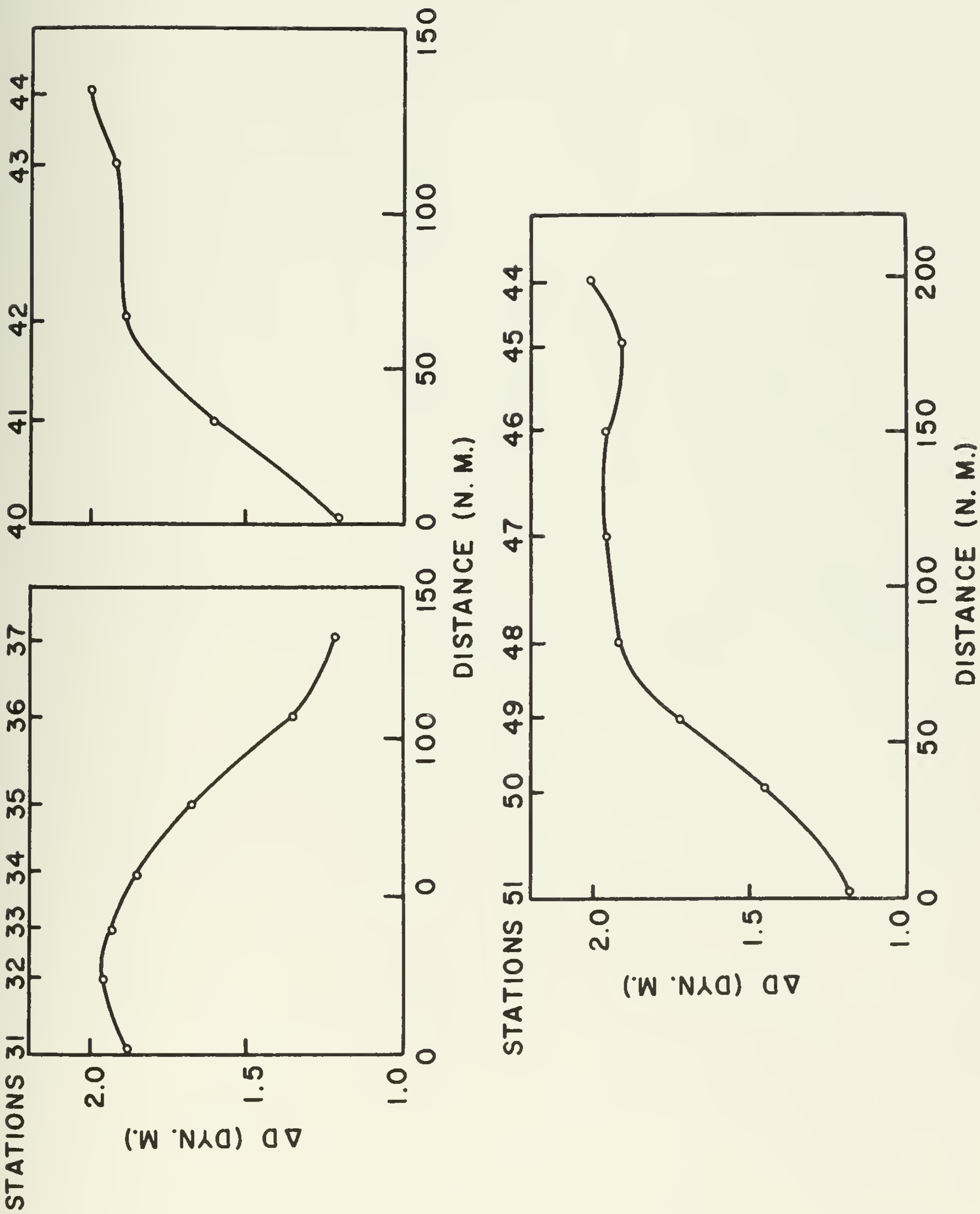

STATIONS 31 32 33 34 35 36 37
ΔD (DYN. M.)
2.0
1.5
1.0
0
0
100
150
40 41 42 43 44
0
50
100
150
DISTANCE (N. M.)
STATIONS 51 50 49 48 47 46 45 44
ΔD (DYN. M.)
2.0
1.5
1.0
0
50
100
150
200
DISTANCE (N. M.)

FIGURE 27

FIGURE 28. Profiles of the sea surface from dynamic computations. Stations 51-65, 11-13 August 1966, ALAMINOS 66-A-11.

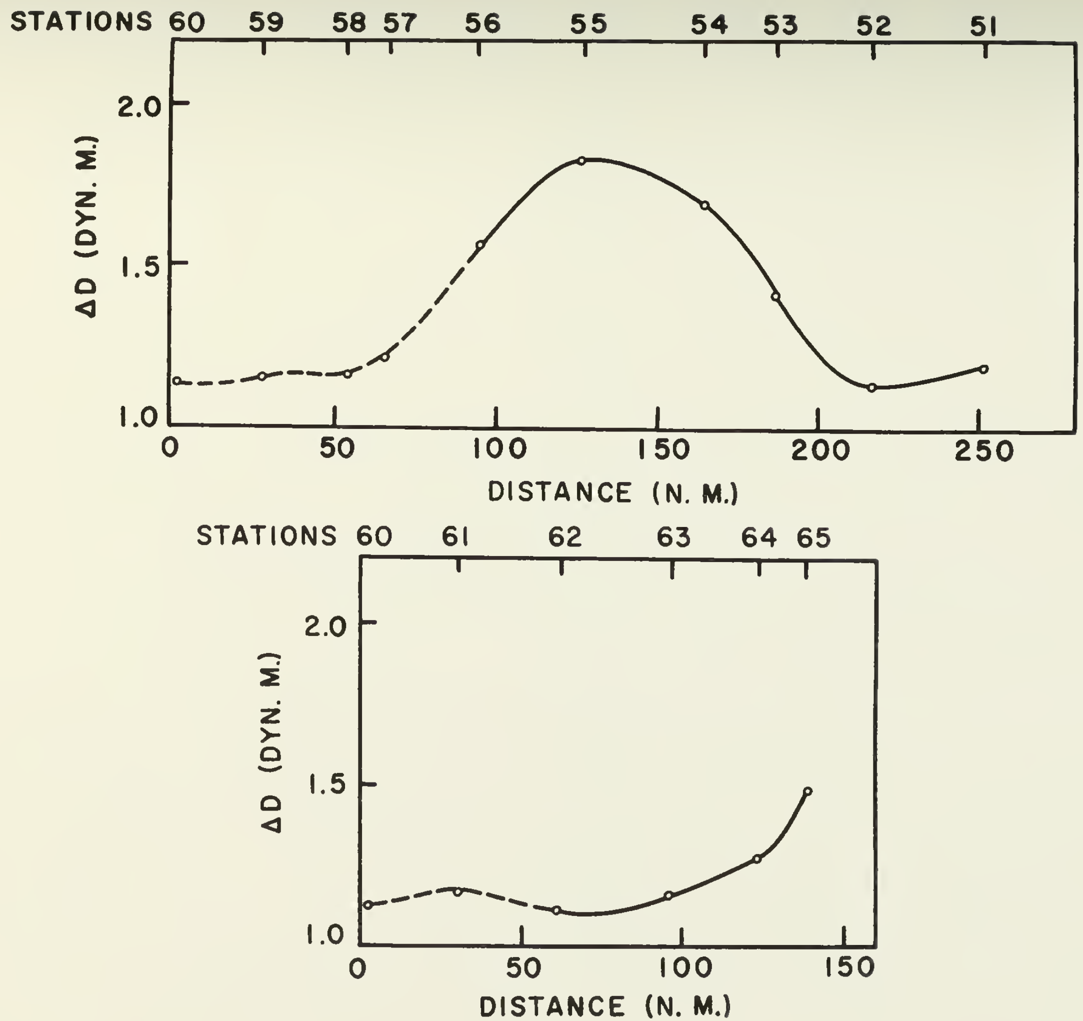

STATIONS 60 59 58 57 56 55 54 53 52 51
ΔD (DYN. M.)
2.0
1.5
1.0
0 50 100 150 200 250
DISTANCE (N. M.)
STATIONS 60 61 62 63 64 65
ΔD (DYN. M.)
2.0
1.5
1.0
0 50 100 150
DISTANCE (N. M.)

FIGURE 28

FIGURE 29. Profiles of the sea surface from dynamic computations, Stations 65-83, 13-16 August 1966, ALAMINOS 66-A-11.

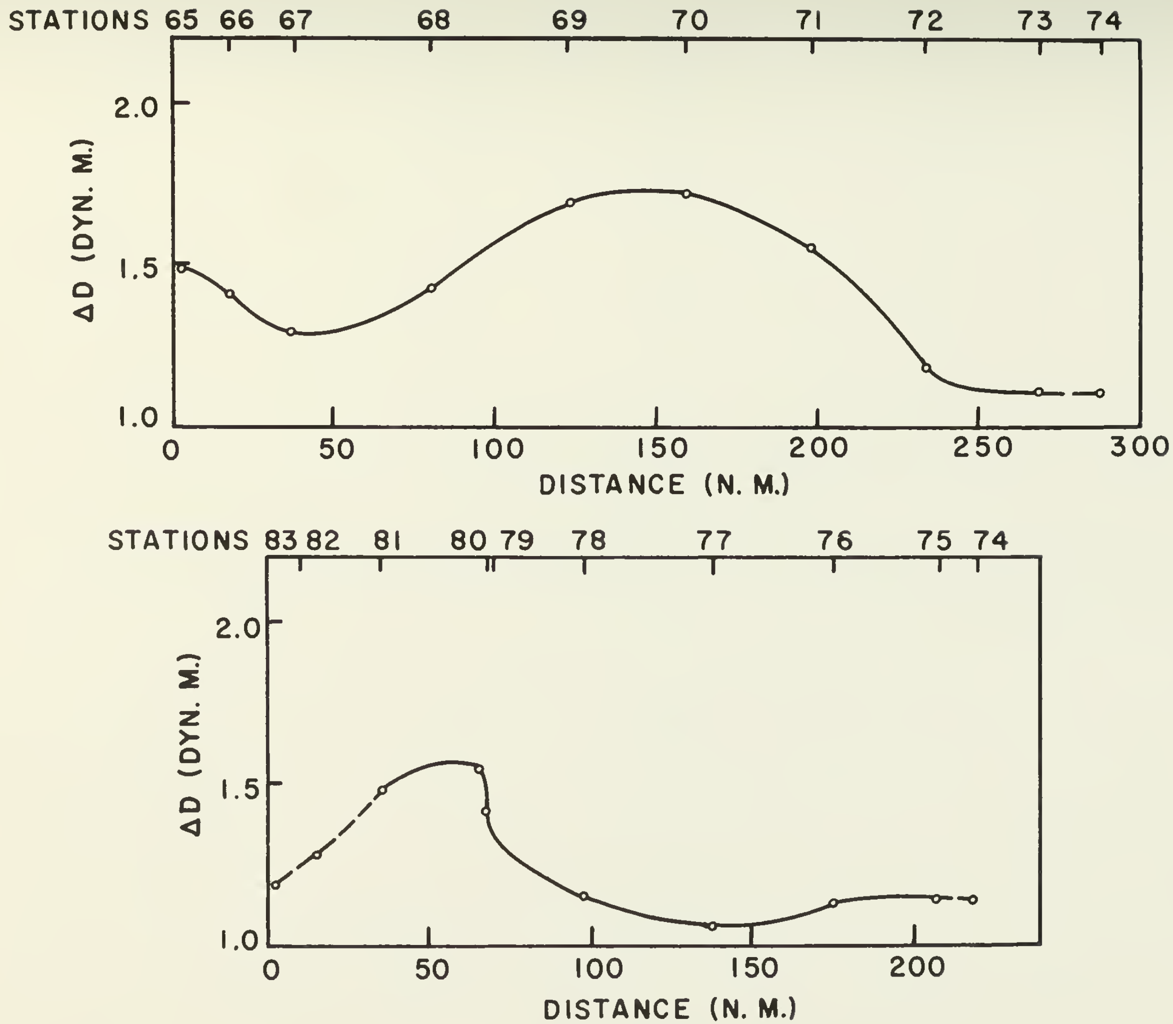
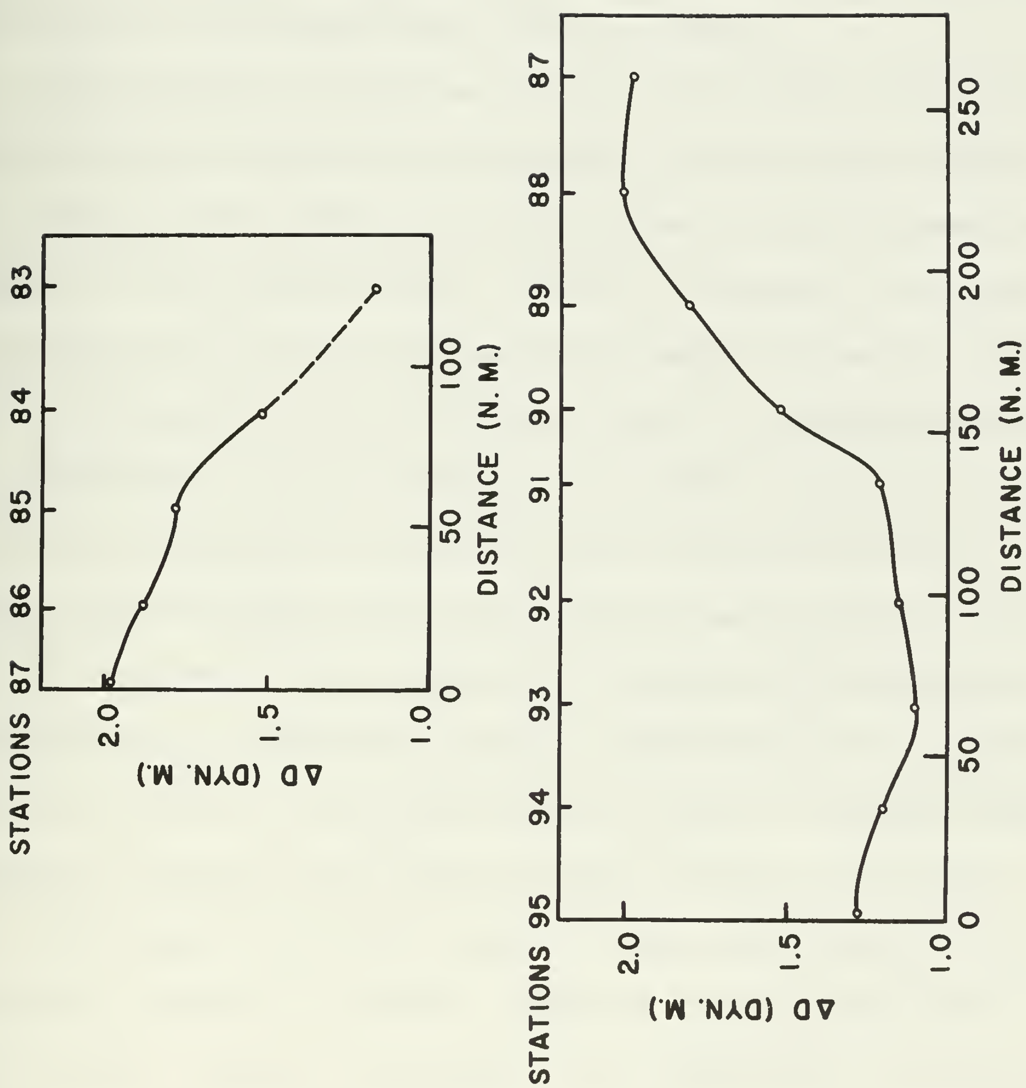

STATIONS 65 66 67 68 69 70 71 72 73 74
ΔD (DYN. M.)
2.0
1.5
1.0
0 50 100 150 200 250 300
DISTANCE (N. M.)
STATIONS 83 82 81 80 79 78 77 76 75 74
ΔD (DYN. M.)
2.0
1.5
1.0
0 50 100 150 200
DISTANCE (N. M.)

FIGURE 29

FIGURE 30. Profiles of the sea surface from dynamic computations, Stations 83-95, 16-18 August 1966, ALAMINOS 66-A-11.



STATIONS 87
86
85
84
83
ΔD (DYN. M.)
2.0
1.5
1.0
0
50
100
DISTANCE (N. M.)
STATIONS 95
94
93
92
91
90
89
88
87
ΔD (DYN. M.)
2.0
1.5
1.0
0
50
100
150
200
250
DISTANCE (N. M.)

FIGURE 30

Northern Loop and the Cuban Loop.

While the contours of the Northern Loop are shown joined in the southwestern quadrant, they may not be truly representative of the flow pattern there. The absence of data in the quadrant permits only the speculative interpretations of Figs. 24 and 25.

Configuration of streamlines in the Yucatan Strait (Fig. 24) is also subjectively presented; unfortunately stations across the western portion of the Strait were not deep enough to permit dynamic computations to the 1000-db surface. In Fig. 25, however, the streamlines depicted in this area are based on dynamic computations to the 300-db surface, but must be viewed with caution, as mentioned above.

Referring to Fig. 24, around both the Cuban Loop and the Northern Loop the separation of the flow into an "inside loop" and a single dumb-bell shaped outer envelope may be made by selecting the 1.5 and 1.6 dynamic meter streamlines to represent the boundaries of these sub-system circulation patterns. The "inside loop" circulation within the Northern Loop, bounded by its 1.6 dyn.m. streamline, has a transport (relative to the 1000-db surface) of 29.3×10^6 m^3/sec. The "inside loop" circulation within the Cuban Loop, bounded by its 1.6 dyn.m. streamline, also has a transport of 29.3×10^6 m^3/sec. These figures represent the average of the summations of all the dynamic computations performed between pairs of stations along the axial legs extending from the centers of these interior gyres out to the 1.6 dyn.m. streamline.

The transport within the envelope around the Northern Loop, com-

puted as above, is 13.4 x 10^6 m^3/sec. The transport within the envelope of the Cuban Loop, based on dynamic computations in the Florida Straits area only due to insufficient information in the Yucatan Strait area, is 11.9 x 10^6 m^3/sec. The latter figure is based on data for just five stations and must be considered as only an estimate of the flow.

A summary of these computations is presented in Table V, with the percentage of the several transports to the total transport indicated.

TABLE V

VOLUME TRANSPORTS WITHIN CUBAN LOOP AND NORTHERN LOOP

	"Inner Loop"	%	Outer Envelope	%	Total	%
Northern Loop	29.3	68.5	13.4	31.5	42.7	100
Cuban Loop	29.3	71.0	11.9	29.0	41.2	100

(Values are x 10^{-6} m^3/sec)

These results are indicative of the state of development of the Eastern Gulf Loop circulation at the time of this cruise; as more of the total transport of the circulation system in the Eastern Gulf of Mexico (taken as a single system) is concentrated within the "inner loops" of both the Northern Loop and the Cuban Loop (and both should be equivalent), these two features become more independent of each

other. At the ultimate state of development, the transport contained in the envelope surrounding the "inner loops" may become insignificant and the Northern Loop may then become separated from the parent Cuban Loop. Without a further source of supply of Right-Hand waters from the inflowing Yucatan Current -- even though the Northern Loop is mostly Right-Hand water within its own circulation -- it cannot maintain itself as a separate identity from the resident Gulf of Mexico waters and probably diffuses slowly into them.

Further dynamic computations of the transport relative to the 1000-db surface between axial stations and the center of the Northern Loop (at St. 88) support the above discussion of the balance of transport in that system. In tabular form, they are:

Station Pairs	Transport
88-92	43×10^6 m^3/sec
88-62	42×10^6 m^3/sec
88-52	45×10^6 m^3/sec
88-73	44×10^6 m^3/sec

These figures are perhaps subject to significant error when consideration is given to the horizontal distances involved between stations (see Fig. 1); nevertheless they illustrate the uniformity of flow around the Northern Loop. When the same axes are used to demonstrate the transport relative to the 300-db surface, the results are similar to those for the 1000-db surface:

Station Pairs	Transport
88-93	12.2 x 10^6 m^3/sec
88-73	12.8 x 10^6 m^3/sec
88-60	11.8 x 10^6 m^3/sec
88-67	9.6 x 10^6 m^3/sec
88-52	11.6 x 10^6 m^3/sec
88-83	14.3 x 10^6 m^3/sec

It is seen that the transport in the upper 300 meters is approximately 35% of that of the water column above 1000 m.

The flow pattern of the Cuban Loop indicates that some inflowing Yucatan Current waters proceed northward, turn sharply south-southeastward near St. 48 to return toward the Cuban coast, and then are diverted back into the Caribbean through the Yucatan Strait. Specifically, the transport between Sts. 43 and 44 is approximately 7.6 x 10^6 m^3/sec, southward, while between Sts. 44 and 45 there is a net transport eastward of 8.5 x 10^6 m^3/sec. Lack of data for this area in the Yucatan Strait (along the 22° N. latitude parallel) precludes definite description of this area, but the suggestion is strong that there may be a closed loop anticyclonic circulation within the Cuban Loop centered at St. 44. The vertical sections for Transect D-D' (Figs. 18, 19, and 20) give some evidence of a southward flow below 400 meters, as mentioned previously. The net transports relative to the 300-db surface between Sts. 43-44 and 44-45 are 0.75 x 10^6 m^3/sec, southward, and 0.9 x 10^6 m^3/sec, eastward, respectively, indicating that the deeper flow dominates the water movements in this region.

The observed (computed relative to the 1000-db surface) outflow-

ing net transport in the Florida Straits (from Sts. 40 to 44) is approximately 45 x 10^6 m^3/sec, eastward. Over half, or 30 x 10^6 m^3/sec, occurs between Sts. 40 and 42. Further, the net transport between Sts. 47 and 52 (from the Cuban Loop northward across the current to the cold tongue of waters extending off the Florida Shelf) is 42 x 10^6 m^3/sec, eastward. Summarizing the transports of several selected cross-current sections, compare:

Station Pairs	Transport
88-52	45 x 10^6 m^3/sec
47-52	42 x 10^6 m^3/sec
40-44	45 x 10^6 m^3/sec

Table VI lists the relative surface currents and net transports derived following the dynamical computational procedures outlined by McLellan (1965). Values relative to both the 300-db and the 1000-db reference levels are tabulated for comparison. Direction of flow may be inferred by reference to the figures discussed in the preceeding sections. All computations were performed utilizing the mean latitude between the stations considered for determination of the Coriolis parameter.

Table VII compares the maximum surface current velocities to the surface current velocities located over the high-salinity core of the Right-Hand waters. It is seen from Table VII that the maximum surface velocities are indicative of the horizontal limit of influence of the Eastern Gulf Loop Current; specifically, the excursion of the left side of the current (facing downstream) is delineated. The maximum

TABLE VI

RELATIVE SURFACE CURRENT VELOCITIES AND VOLUME TRANSPORTS BETWEEN STATIONS

[BASED ON DYNAMIC COMPUTATIONS TO THE INDICATED REFERENCE LEVEL]

Stations	Current Velocity				Volume Transport	
	cm/sec		kts		$m^3/sec(x10^{-6})$	
	1000db	300db	1000db	300db	1000db	300db
28						
	--	139	--	2.7	--	4.7
29						
	--	82	--	1.6	--	3.9
30						
	--	103	--	2.0	--	2.6
31						
	29	23	0.6	0.5	2.3	1.7
32						
	22	18	0.4	0.4	1.0	0.4
33						
	87	11	1.7	0.2	6.6	0.4
34						
	81	43	1.6	0.8	11.6	3.2
35						
	102	77	2.0	1.5	12.7	5.0
36						
	44	33	0.9	0.7	4.0	2.3
37						
	--	--	--	--	--	--
40						
	102	79	2.0	1.5	13.5	6.1
41						
	87	43	1.7	0.8	19.0	4.4

TABLE VI (continued)

RELATIVE SURFACE CURRENT VELOCITIES AND VOLUME TRANSPORTS BETWEEN STATIONS

[BASED ON DYNAMIC COMPUTATIONS TO THE INDICATED REFERENCE LEVEL]

Stations	Current Velocity				Volume Transport	
	cm/sec		kts		$m^3/sec(x10^{-6})$	
	1000db	300db	1000db	300db	1000db	300db
42						
	5	1	0.1	0.0	4.2	0.2
43						
	44	17	0.9	0.3	7.7	0.8
44						
	51	19	1.0	0.4	8.5	0.9
45						
	7	11	0.2	0.2	0.1	1.0
46						
	1	3	0.0	0.1	1.4	0.4
47						
	11	6	0.2	0.1	1.3	0.8
48						
	63	34	1.3	0.7	9.8	2.5
49						
	106	68	2.1	1.3	13.4	4.3
50						
	68	49	1.3	1.0	10.9	3.6
51						
	10	1	0.2	0.0	4.4	0.5
52						
	74	53	1.4	1.0	10.8	3.9
53						
	101	60	1.9	1.2	13.5	3.4

TABLE VI (continued)

RELATIVE SURFACE CURRENT VELOCITIES AND VOLUME TRANSPORTS BETWEEN STATIONS

[BASED ON DYNAMIC COMPUTATIONS TO THE INDICATED REFERENCE LEVEL]

Stations	Current Velocity				Volume Transport	
	cm/sec		kts		$m^3/sec(x10^{-6})$	
	1000db	300db	1000db	300db	1000db	300db
54						
	31	18	0.7	0.3	6.5	2.3
55						
	66	36	1.2	0.7	14.3	4.0
56						
	---	61	---	1.2	---	4.2
57						
	---	22	---	0.4	---	1.5
58						
	---	16	---	0.3	---	0.2
59						
	---	7	---	0.1	---	0.4
60						
	---	5	---	0.1	---	0.4
61						
	---	0	---	0.0	---	0.0
62						
	6	8	0.1	0.2	0.9	0.0
63						
	35	32	0.7	0.6	2.8	2.2
64						
	116	73	2.3	1.4	9.5	2.9
65						
	35	19	0.7	0.4	3.3	0.9

TABLE VI (continued)

RELATIVE SURFACE CURRENT VELOCITIES AND VOLUME TRANSPORTS BETWEEN STATIONS

[BASED ON DYNAMIC COMPUTATIONS TO THE INDICATED REFERENCE LEVEL]

Stations	Current Velocity				Volume Transport	
	cm/sec		kts		$m^3/sec(x10^{-6})$	
	1000db	300db	1000db	300db	1000db	300db
66						
	50	46	1.0	0.9	3.0	2.2
67						
	24	23	0.5	0.4	2.6	2.4
68						
	51	29	1.0	0.6	13.6	3.7
69						
	8	19	0.2	0.0	4.2	0.0
70						
	39	19	0.8	0.4	11.2	2.5
71						
	80	58	1.6	1.1	13.2	5.1
72						
	19	18	0.4	0.3	0.3	1.0
73						
	--	1	---	0.0	---	0.1
74						
	--	27	---	0.5	---	0.8
75						
	2	1	0.0	0.0	1.0	0.1
76						
	13	9	0.2	0.2	2.6	0.9
77						
	20	12	0.4	0.2	4.9	1.3

TABLE VI (continued)

RELATIVE SURFACE CURRENT VELOCITIES AND VOLUME TRANSPORTS BETWEEN STATIONS

[BASED ON DYNAMIC COMPUTATIONS TO THE INDICATED REFERENCE LEVEL]

Stations	Current Velocity				Volume Transport	
	cm/sec		kts		$m^3/sec(x10^{-6})$	
	1000db	300db	1000db	300db	1000db	300db
78						
	75	54	1.5	1.1	10.9	3.6
79						
	40	38	0.8	0.7	2.1	2.4
80						
	--	19	---	0.4	---	1.8
81						
	--	88	---	1.6	---	3.7
82						
	--	78	---	1.5	---	3.2
83						
	--	87	---	1.7	---	8.0
84						
	78	50	1.5	1.0	14.5	4.6
85						
	25	7	0.5	0.1	7.2	1.0
86						
	32	15	0.6	0.3	5.0	1.0
87						
	5	3	0.1	0.1	3.8	0.1
88						
	48	21	0.9	0.4	13.6	2.6
89						
	70	33	1.4	0.6	15.7	3.5

TABLE VI (continued)

RELATIVE SURFACE CURRENT VELOCITIES AND VOLUME TRANSPORTS BETWEEN STATIONS

[BASED ON DYNAMIC COMPUTATIONS TO THE INDICATED REFERENCE LEVEL]

Stations	Current Velocity				Volume Transport	
	cm/sec		kts		$m^3/sec(x10^{-6})$	
	1000db	300db	1000db	300db	1000db	300db
90						
	107	8	2.1	0.2	11.0	4.5
91						
	20	16	0.4	0.3	2.6	0.8
92						
	18	2	0.3	0.0	5.8	0.8
93						
	36	24	0.7	0.5	5.4	4.2
94						
	20	12	0.4	0.2	3.7	1.5
95						

For Station Locations, See Figure 1.

TABLE VII

COMPARISON OF MAXIMUM SURFACE CURRENT VELOCITIES AND SURFACE CURRENT VELOCITIES OVER RIGHT-HAND WATER CORE

Area	Maximum Velocity cm/sec(kts)	Stations	Velocity Over Core cm/sec(kts)	Stations
Yucatan Strait	102 (2)	35-36	81-87 (1.6-1.7)	33-35
Florida Strait	102 (2)	40-41	87 (1.7)	41-42
Cuban Loop	106 (2.1)	49	6 (0.2)	45-48
Northern Loop:				
	101 (1.9)	54	66 (1.2)	55
	116 (2.3)	64	35 (0.7)	65
	107 (2.1)	90	48 (0.9)	88

(For Locations of Stations, See Figure 1.)

velocities observed on this cruise were always to the left of the salinity core of the Right-Hand waters, over the maximum gradients of isolines. Left-Hand waters were found immediately to the left of the maximum velocities.

Figure 26, isobath contours of the 22° C. isotherm, illustrates the general flow patterns of the Northern Loop and the Cuban Loop. The 200-meter isobath gives good agreement with the vertical sections discussed previously in the location of the high-salinity core of the Right-Hand Eastern Gulf Loop waters.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

In the late summer of 1966 the intrusion of the Eastern Gulf Loop Current into the Gulf was at its maximum, covering nearly the entire East Gulf basin and dominating the distribution of several distinct water masses contained within the area. The Right-Hand Eastern Gulf Loop waters, with their distinctive high-salinity core at 175-225 meters depth, constituted a large percentage of the waters of the Eastern Gulf Loop. At the boundary between the Eastern Gulf Loop Current circulation and the resident waters of the Gulf of Mexico, Left-Hand waters prevailed. These two water masses may mix to form an intermediate water mass having the characteristic T-S relationship of Western Gulf of Mexico waters. The differences in these water masses was especially prevelant in the upper 300 meters, as depicted in their characteristic T-S relationships, but significant differences were perceptible down to the deepest depths observed (1200 meters) on the cruise. The variations of temperature, salinity, and sigma-t with depth, as presented in several vertical sections across the flow of the Eastern Gulf Loop Current, indicated that while this Loop Current phenomena is most readily recognizable by the property distributions in the upper 300 meters, its presence is indicated far below this relatively shallow surface layer.

The warm, high-salinity core of the Right-Hand waters (salinities

greater than 36.6°/oo) exhibited an elliptical cross-section which varied in thickness and lateral dimensions. The core dimensions observed ranged from 40 meters (in the Yucatan Strait) to 95 meters (in the Northern Loop) for the thickness and 80-104 n.m. (148-193 km) in lateral extent for the same locations. The Cuban Loop was almost exclusively Right-Hand water, with core dimensions of 35 meters (thickness) and 148 n.m. (274 km) (length along a northwest-southeast axis). This enormous mass of warm, high-salinity waters in the Gulf is associated with steep gradients in the isolines of mass and property distribution and with high-velocity flows to the left of the Right-Hand water salinity core. Stations having T-S relationships representative of the Left-Hand waters were found to the left (facing downstream) of these locations of maximum gradients. The mixed layer depth observed during this cruise was an average of 30 meters, with a maximum depth of 40-50 meters noted at some stations. This mixed layer effectively masked the presence of the Right-Hand and Left-Hand waters beneath. Attempts to correlate observed surface temperature and salinity measurements with the Right-Hand and Left-Hand waters resulted in no definitive relationships. Thus in the presence of the nearly homogeneous late summer mixed layer, surface temperature and salinity values are of no assistance in locating the Eastern Gulf Loop waters.

At the time of this cruise, in early August, the Eastern Gulf Loop Current was constituted of two distinct parts. An elongated, anticyclonic loop off the northwest tip of Cuba was overshadowed in

prominence only by the large, well-developed anticyclonic Northern Loop circulation centered near 26° N., 88° 30' W. Surface current velocities, as computed by dynamic computations, were as high as 116 cm/sec (2.3 kts) in the swiftest protions of the Current, with net volume transports of nearly 45 x 10^6 m^3/sec observed in both the Northern Loop and Cuban Loop circulations. Further, the circulation patterns consisted of somewhat isolated closed anticyclonic flows within both the Cuban Loop and the Northern Loop; these interior flows were enclosed by an envelope surrounding the entire Eastern Gulf Loop Current system. Transports confined to the interior circulations were equivalent, being about 29 x 10^6 m^3/sec, while the transport in the envelope enclosing them was about 13 x 10^6 m^3/sec. Nearly 35% of the flow of the water mass movement was contained in the upper 300 meters. Leipper (1967) believes that the growth of the Eastern Gulf Loop circulation in time, space, and intensity may be accomplished by gradual entrapment of waters from the surrounding envelope into the interior circulations. If such is the case, then the relative a-mounts of the transport contained within each of these flows might be indicative of the stage of development of the Eastern Gulf Loop Current. In particular, at the time of this cruise, the Eastern Gulf Loop Current might be considered as having attained over two-thirds of its maximum potential growth.

While the observed surface temperature and salinity were of no value at the time of this cruise in determining the presence of the Eastern Gulf Loop Current in the underlying waters, there are several

excellent indices which are likely valid during any season. The depth of the 22° C. isotherm falls between 175-225 meters coincident with the presence of the warm, high-salinity core of the Right-Hand waters. (Compare Figs. 24 and 26.) Further, the temperature at 200 meters depth is likewise a reliable index to the salinity core of these waters; a temperature range of 20-23° C. was always associated with the most intense representation of the salinity core. For temperatures below about 16.5° C. at 200 meters, the waters were Left-Hand. In the intermediate temperature span (16.5-20° C.), the delineation between the two water masses is questionable. Measurement of the above parameters is readily accomplished with standard oceanographic equipment (bathythermograph).

B. Recommendations

Further knowledge of the detailed behavior of the Eastern Gulf Loop Current and the relationships between its water masses and the resident waters of the Gulf of Mexico demands that physical oceanographic investigations henceforth be as nearly synoptic as possible. Concentrated analyses of the upper 300 meters must be performed to realize the full significance of the water mass and property distributions that are suggested in this important layer.

The area in the Yucatan Strait must be surveyed in detail to provide complete coverage of the Eastern Gulf Loop Current at its very introduction into the Gulf. The continuation of Cochrane's work in this area (1961, 1962, 1963, 1965, 1966) should prove especially

valuable.

While the salinity/temperature/depth recorder (STD) is theoretically the ideal instrument for rapid synoptic surveying of the primary oceanographic properties, there are several errors associated with its use which presently limit its effectiveness in accurate water mass analysis (see Appendix A). The STD should be considered as an auxiliary to the classical Nansen bottle hydrocast and bathythermograph techniques of measuring the water structure. The minute detail of the water property distribution as recorded by the STD is not essential to the synoptic study of large-scale features. However, the use of the STD for detailed study of the upper 300 meters, in which severe vertical temperature and salinity gradients are significant, does have promising value. For the present, then, its primary use should be in obtaining a rapid analog record of the salinity and temperature structures -- a "running fix" on the waters traversed, so to speak -- until an area requiring absolute and reliable data collection is encountered. Then the standard hydrocast should be implemented. Following this _modus operandi_, the STD can save valuable cruise time in finding the waters of interest; more time is then available for a thorough investigation by conventional means of the mass and property distributions of the water column.

An analysis of comparative representation of the water mass temperature and salinity structure as measured concurrently by the STD and by a standard hydrocast must be made at the earliest opportunity. A large amount of data should be utilized to minimize the

influence of some gross STD errors which are likely to appear. The current operational accuracy, reliability, and repeatability of the STD values of temperature and salinity must be established. Further, errors in representative quantitative parameters utilizing these temperatures and salinities in their computation (viz., specific volume anomaly, sigma-t, geopotential anomaly, volume transport) must be scaled to the variations found between the STD and hydrocast data. Only after these analyses have been performed can the STD data be used without reservation.

APPENDIX A

STD SYSTEM PERFORMANCE EVALUATION

1. System Description. The salinity/temperature/depth (STD) continuous profile recording system, manufactured by the Hytech Products Division of the Bissett-Berman Corporation, San Diego, California, consists of a compact electronics sensors unit containing transducer assemblies for direct measurement of the *in situ* temperature and salinity (conductivity), supporting shipboard console equipment (power supplies, signal converters, amplifiers), and a dual output system. Either punched tape (digital) or graph (analog) data presentation is available from the installation arrangement aboard the R/V ALAMINOS. Complete details on the Hytech Model 9006 STD may be found in the manufacturer's brochures or in the literature (Brown, 1963, 1964; Brown and Hamon, 1961; Hamon and Brown, 1958). System specifications are given in Table A-I.

Data output format utilized for ALAMINOS 66-A-11 was analog; for each lowering of the sensor package (by its attached electronics cable) a graph of continuous temperature and salinity profiles versus depth was obtained (Fig. 31). Selected data points were then visually read and recorded for subsequent data processing by computer methods.

The STD output, in either analog or digital form, requires correction of the *in situ* salinity values due to the method of measurement. Basically, an inductively coupled conductivity sensor (probe)

FIGURE 31. Sample Salinity/Temperature/Depth (STD) analog record. Grid resolution of graph paper indicated in upper left corner. Salinity, temperature, and depth scales shown (used throughout ALAMINOS 66-A-11) may be changed for larger-scale recording of the *in situ* water structure. This particular analog record was observed at Station 88 (see Figure 1). Illustration is approximately two-thirds recorded size.

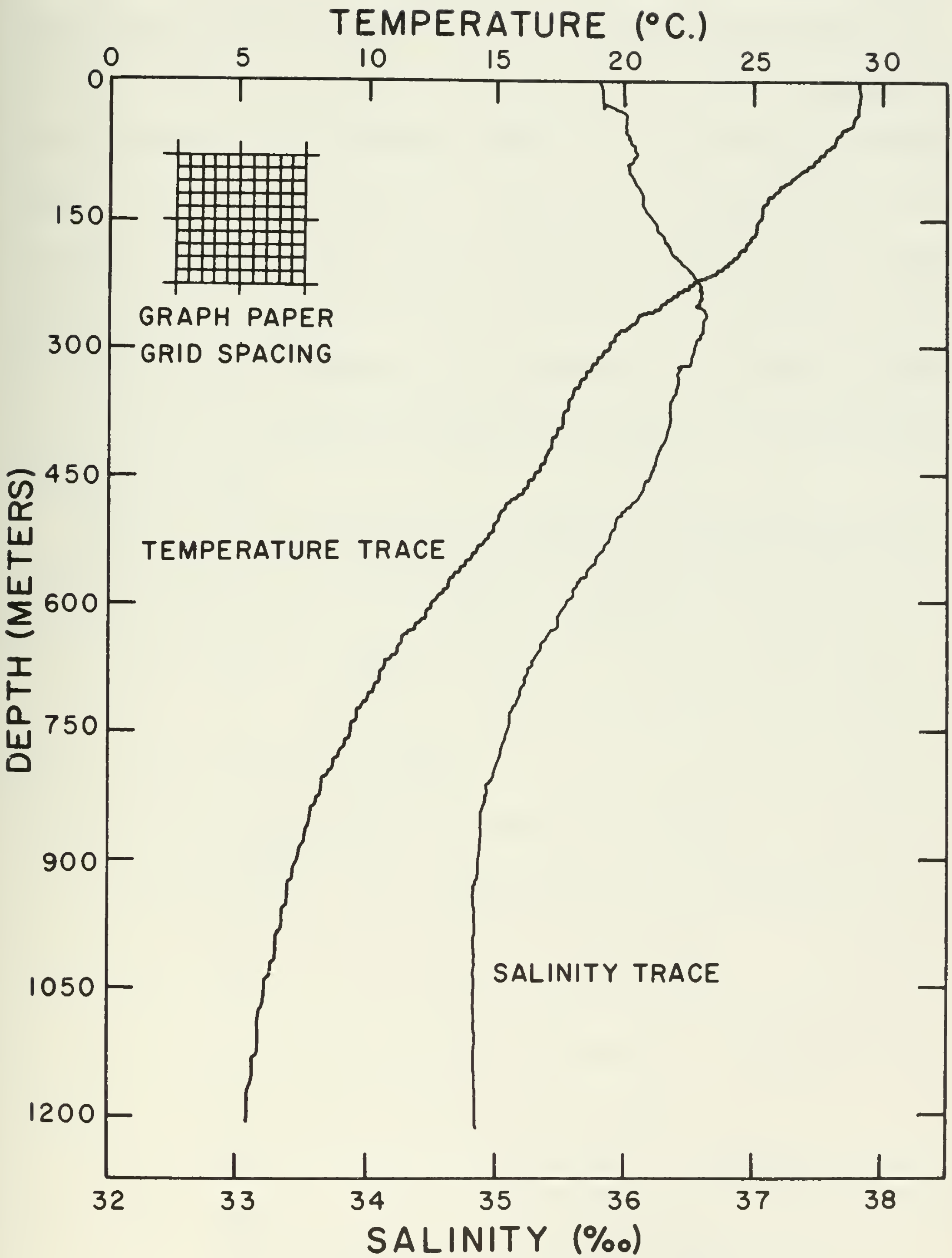

TEMPERATURE (°C.)
0
5
10
15
20
25
30
0
150
300
450
600
750
900
1050
1200
DEPTH (METERS)
GRAPH PAPER
GRID SPACING
TEMPERATURE TRACE
SALINITY TRACE
32
33
34
35
36
37
38
SALINITY (‰)

FIGURE 31

measures the sea water conductivity; the output is converted into a proportional salinity signal value via transduction and electronic filtering. As conductivity is a function of temperature and pressure, these properties have significant effect on the recorded STD salinity output. Therefore, the corrections which must be applied involve the temperature gradient field with depth and the nominal pressure effect caused by the falling velocity of the sensor unit through the water. The latter effect is caused by the formation of a turbulent boundary layer around the temperature compensation probe for the conductivity transduction sensor.

Following the procedure of Gaul (1967), as adapted from Brown (1964), the formula for the corrected salinity is

$$S = S^*(1 - K_R K_G \frac{\partial T}{\partial Z} (V\Delta\tau + h)) \qquad (1)$$

where S = corrected salinity

S^* = <u>in situ</u> salinity as read by the STD

$K_R = \frac{R}{S} (\frac{\partial R}{\partial S})^{-1}$, the conductivity ratio coefficient

$K_G = \frac{1}{G} \frac{\partial G}{\partial T}$, the conductivity coefficient

T = temperature, degrees Centigrade

Z = depth below surface of the water

V = falling velocity of the sensor unit through the water

$\Delta\tau$ = difference in time constants (relative response rates) of the temperature compensation probe and the conductivity probe (taken as 0.35 seconds)

h = distance of temperature compensation probe above conductivity probe ($h = 0$ for cruise ALAMINOS 66-A-11)

K_R, the conductivity ratio coefficient (as a function of salinity), is determined from the empirical relationship

$$K_R = \frac{\alpha + \beta S + \delta S^2}{\beta S + 2\delta S^2}\ , \tag{2}$$

where $\alpha = 0.038011$

$\beta = 0.029435$

$\delta = 0.0000557.$

K_G, the conductivity coefficient (as a function of temperature), is a curvilinear function and may be determined directly from a graph (Gaul, 1967) or may be computed for specific values of temperature using a least squares quadratic fit to the graph data. Treatment of data for this cruise utilizes the latter method, with the resulting equation

$$K_G = A1 + A2(T) + A3(T^2), \tag{3}$$

where

$A1 = 0.029903286$

$A2 = -0.0005723$

$A3 = 0.000006648.$

The gradient of temperature with depth, $\frac{\partial T}{\partial Z}$, may be computed utilizing either the forward difference or central difference operators of numerical analysis techniques (Froberg, 1965). Data corrected herein utilizes the latter criterion:

$$\left(\frac{\partial T}{\partial Z}\right)_i = \frac{T_{i+1} - T_{i-1}}{2(\Delta Z)} \tag{4}$$

where ΔZ is the increment between successive depth levels and

the i^{th} level is the one for which the gradient is desired.

2. Factors Affecting Performance. The fall rate, V, of the sensor unit through the water is measured by the STD recorder operator noting the stopwatch time at which a specific depth below the surface is passed during descent of the sensor unit. The descent speed in meters per second is computed from this simple timing process. From Equation (1) it is evident that as the speed of descent of the sensor unit increases, the higher the corrected salinity will be. Note that $\frac{\partial T}{\partial Z}$, in most instances, is a negative quantity, since temperature is generally monotonically decreasing with increasing depth. K_R and K_G varied only slightly over the temperature and salinity ranges encountered during this cruise in the Gulf; therefore the critical portions of the correction formula are the temperature gradient factor and the fall rate of the unit. The latter is the only condition over which the oceanographer has any control. A constant speed winch was not available for use with the STD on ALAMINOS 66-A-11; STD casts were made using the installed oceanographic winch. Resulting fall rates on this cruise were consequently highly variable and were dependent on operator proficiency. For some casts only the time of arrival at the bottom (of the cast) was noted (rather than the complete notation of times of passing various selected depth levels) or timing data was only partially completed. Fall rates, in general, were acceptable (between 1.0-1.5 meters per second), but several casts were made at fall rates of over 3.0 meters per second.

Such casts would produce corrected salinities higher than the majority observed during the entire cruise. When subsequently plotted on a T-S diagram, several stations exhibited salinity deviations from the normal trend. These stations were suspect and were disregarded due to higher fall rates associated with portions of their descents.

3. Data Reduction. One distinct advantage of the STD system output is its continuous profiles of temperature and salinity versus depth; the fine gradient structure presented allows the oceanographer a wide selection of interesting areas for investigation. Selected values of temperature and salinity may be chosen at standard depth levels or at those depths where significant changes in gradient of either temperature or salinity occur. Inasmuch as the salinity correction formula requires that a temperature gradient be computed for each set of values so selected, depth levels must be chosen such that there are equal intervals between successive points (Equation (4)). Smaller depth intervals (a few meters or less) yield better approximation of the actual temperature structure present in the water; closely spaced sampling points are mandatory for precise interpretation of shallow water (300 meters) analog output, while in deeper waters (where the gradients are small) a wider spacing of points may be justifiably employed.

The STD itself records a false output when it senses a large gradient in temperature; the relative response rates of the various sensing probes (Table A-1) are such that the salinity is being electronically corrected and compensated for a large temperature change

over a small depth interval, but the temperature compensation applicable to the salinity value noted at level Z is being applied to the salinity value noted at level Z + ΔZ. The resulting analog output shows an abnormally large excursion of the salinity trace in the areas of such temperature gradients. Fortunately, most of these abnormal salinity errors are recognizable and may be simply corrected right on the analog graph by hand-fairing a smooth curve along the sawtooth salinity trace. No significant errors are introduced by this rather subjective method (Gaul *et*. *al*., 1966).

TABLE A-I

HYTECH Model 9006 System Specifications

PARAMETER	ACCURACY	RESOLUTION	RESPONSE TIME
Salinity	± 0.03°/oo on all ranges	Infinite	0.35 sec. (limited by temp. probe)
Temperature	± 0.05°C. incl. non-linearity and repeatability	Infinite	0.35 sec.
Depth	± 0.5% of full scale incl. non-linearity, repeatability, and temperature effects	Infinite	0.2 sec.

There are thus three major sources of error in the salinity correction procedure. First, there may be unusually large or abrupt changes in the fall rate. These might cause an unusual scatter in the corrected salinities observed during a cruise. Second, there is

the problem of extracting the right data points from the analog graph to insure good representation of the gradients (especially those gradients in the shallow layers below the seasonal thermocline). Third, there is the chance of introducing errors through incorrect reading of the graphs; caution must be exercised when there are unusual salinity fluctuations on the graph. The hand fairing technique mentioned above is then especially adaptable but at the same time is a possible source of further error.

4. Data Processing. Considering the objectives of this study, values of temperature and salinity were read from the analog graphs at 15 meter intervals from the surface to 300 meters, and at 75 meter intervals from 300-1200 meters (or to the deepest descent level). This procedure minimized the misrepresentation of sudden changes in the temperature gradient in the shallower layers. Salinity values to two decimal place accuracy were read after hand-fairing the "best fit" curve.

A data processing program, written in IBM-IBSYS/FORTRAN IV machine processor language format (see Appendix C.), was authored and used not only to compute the corrected salinity but also to compute several other parameters of the mass and property distributions for each of the 93 STD stations occupied on this cruise. Data processing was accomplished at the Data Processing Center, Texas A&M University.

5. STD Error Analysis. Stations having both STD and hydrocast

data (Table I) were plotted on the same T-S diagram for comparison. The STD T-S curves were generally parallel to the hydrocast T-S curves over the entire cast depth range, indicating good performance of the STD system in representing the structure of the water column.

All STD T-S curves plotted at lower temperature and salinity values than those of the hydrocast curves; mean temperature and salinity corrections of + 0.09° C. and + 0.056°/oo were determined necessary to bring the STD curves into agreement with the hydrocast curves. An elementary statistical analysis (Student-t Test) was performed to determine the validity of the negative bias in the mean values of temperature and salinity errors (Ostle, 1963). The test showed the error was significant for both temperature and salinity, with the standard deviations of the errors being 0.08 (salinity) and 0.22 (temperature).

Another relatively simple error check was performed. Computations of dynamic height anomaly, relative current velocity, and volume transport for the sea surface relative to the 1000-db surface were made for seven sets of stations using both the computer (IBM 7094) output corrected data (STD values) and the same data with the temperature and salinity correction factors (specified above) added. The maximum dynamic height anomaly difference resulting was + 0.0014 dyn.m., representing a + 0.05% error. These figures are reasonable when the corrections applied are examined in their effect on the shift of the T-S curve. Since both increase, the entire curve is moved along nearly parallel to the isopycnals of sigma-t (density). The

changes in the dynamic computations caused by this T-S curve shift should be small. The magnitude of the changes in this case is insignificant in its effect on dynamic computations.

It is not advisable, however, to use STD output uncorrected for deviation from the normal hydrocast data, because the depths at which specific values of temperature and salinity (and hence density) are observed might be subject to significant error and could cause invalid conclusions in the interpretation of results. All data used in preparing vertical sections, graphs, contours, and other visual aid treatments of the water mass properties observed on this cruise have been corrected to the normal hydrocast data concurrently observed. As the corrections applied are the mean values of all deviations noted, there may be some stations that are not truly representative of the actual water conditions at their location. For purposes of this investigation, however, this method of treatment of the data is not believed to have affected the interpretation of results.

APPENDIX B

COMMENTS ON STD SALINITY CORRECTION PROGRAM

Appendix C contains the IBSYS/FORTRAN IV machine processor language data processing program utilized in this study for correction of STD salinities and computation of the several oceanographic parameters for the determination of mass and property distributions of the Gulf waters.

The program is arranged in three sections. The main section determines the corrected salinity for the STD recorded *in situ* salinity using the formulas defined in Appendix A. Data input is arranged so that the program reads temperature, salinity, and fall rate of the STD sensor unit for each depth level selected for each station. The program has the capacity as written to handle a total of 250 selected depths for one or two different constant depth intervals between successive sampling depths. With two constant depth intervals, the program handles two zones separately in computation. Comment cards at the head of the program (see Appendix C.) give detailed instructions for preparing the data for handling.

Following computation of a corrected STD salinity, the program computes sigma-t, the thermosteric anomaly and its corrections for temperature-pressure and salinity-pressure effects, the geopotential depth at each level, and the transport potential function for each level. Summations of dynamic depths and transport potential function are made from the surface to the deepest level sampled with inter-

mediate level summations shown. This procedure (McLellan, 1965) permits the determination of the dynamic height and transport potential function of the sea surface or any intermediate level relative to any chosen reference level. Using the definitions of Nowlin (unpublished memoranda), equations representing the procedure are:

$$\sum_{Z_1}^{Z_2} \Delta D \doteq \int_{P_1}^{P_2} \delta \, dp = D \Big|_{Z_1}^{Z_2} , \quad Z_1 < Z_2 \tag{1}$$

$$\sum_{Z_1}^{Z_2} \Delta Q = \int_{Z_1}^{Z_2} \int_{P_1}^{P_2} \delta \, dpdz = Q \Big|_{Z_1}^{Z_2} \tag{2}$$

where D = geopotential anomaly between pressure surfaces Z_1 and Z_2

δ = specific volume anomaly

dp = pressure differential between depth Z_1 and Z_2

dz = depth difference beween Z_1 and Z_2

Q = volume transport potential between pressure surfaces Z_1 and Z_2

The equation for finding the transport potential between levels Z_1 and Z_2 relative to currents at some reference level Z_R is:

$$Q_{Z_R} \Big|_{Z_2}^{Z_1} \equiv \int_{Z_2}^{Z_1} \int_{P_R}^{P} \delta \, dpdz \tag{3}$$

or

$$Q_{Z_R}\Big|_{Z_2}^{Z_1} = (Z_2 - Z_1)\, D\Big|_0^{Z_R} + Q_0\Big|_0^{Z_1} - Q_0\Big|_0^{Z_2} \qquad (4)$$

Equations (1) through (4) are valid with any self-consistent system of units.

The output of the parameters discussed above constitutes the minimum output of the program.

The remaining two sections are optional. One is a routine utilizing the minimum output described above to determine the values at standard depths of the same parameters (*i.e.*, temperature, salinity, sigma-t, etc.) previously specified. Lagrangian four-point interpolation (Froberg, 1965) and linear interpolation are employed to obtain the values of temperature and salinity at the standard depth levels. The other parameters are then computed using these interpolated values of temperature and salinity. If a standard depth selected coincides with a level used for computation in the main program (minimum output section), that data is stored without recomputation. Finally, dynamic heights and transport potential of the sea surface relative to the predetermined reference level (specified in the program) are computed and stored. The program presently specifies the 1000-db surface as the reference level. If a cast does not reach the reference level, no dynamic heights nor transport potential are computed, but other values at standard depths are.

The remaining option computes the depths at which selected val-

ues of sigma-t are found, the values of the minimum and maximum salinities and their corresponding temperatures and depths, and the depth of the 22° C. isotherm. Other isotherms may be substituted by changing a single card in the program.

In the main program, the equations for computation of sigma-t and the specific volume anomaly are those of Knudsen (1905) and Sverdrup (1933) as presented in H.O. 614, Processing Oceanographic Data (LaFond, 1951).

The corrections to the specific volume anomaly for temperature-pressure and salinity-pressure effects are computed utilizing an equation having varying coefficients, depending on the integer value of temperature or salinity which lies closest to the values for which computation is desired. Data in Tables IVa and Va (Sverdrup et. al., 1942) is linearly related in depth (pressure) to each whole value of temperature or salinity. For each linear relationship in this family of straight lines, then, a set of linear coefficients was determined. To determine the appropriate correction (temperature-pressure or salinity-pressure), all that was necessary was the selection of the right set of coefficients and thence their use in a simple equation. These routines, all developed using computer computations, are described in mathematical (machine) language in the program in Appendix C.

A P P E N D I X C

STD SALINITY CORRECTION PROGRAM

```
$IBJOB
$IBFTC STD
C
C     THIS PROGRAM MAY BE RUN IN EITHER -AGGIE- OR -IBSYS/FORTRAN IV.
C
C     THIS PROGRAM CORRECTS THE INDICATED SALINITIES AS READ FROM THE
C     GRAPH OUTPUT OF THE CONTINUOUS RECORDING SALINITY/TEMPERATURE/
C     DEPTH INSTRUMENT (BISSET-BERMAN CORP.),UTILIZING INDICATED
C     TEMPERATURE AND CORRESPONDING FALL VELOCITY OF THE INSTRUMENT
C     THROUGH THE WATER AT CONSTANT DEPTH INTERVALS, IN TWO ZONES,
C     PERMITTING A DEPTH INTERVAL CHANGE IF DESIRED FOR GREATER
C     ACCURACY IN AREAS OF MARKED TEMPERATURE GRADIENT WITH DEPTH.
C
C     THIS PROGRAM CANNOT BE USED TO CORRECT S/T/D SALINITIES READ FROM
C     S/T/D GRAPHS AT STANDARD DEPTHS. THERE ARE SUCH PROGRAMS
C     AVAILABLE ON FILE AT THE DATA PROCESSING CENTER. CONTACT MR.
C     W. MCMATH FOR INFORMATION.
C
C     MINIMUM OUTPUT OF THIS PROGRAM INCLUDES FOR EACH STATION DEPTH
C     LEVEL, TEMPERATURE, INDICATED SALINITY, CORRECTED SALINITY,
C     SALINITY DIFFERENCE, SIGMA-T, THERMOSTERIC ANOMALY, AND DYNAMIC
C     HEIGHT AND TRANSPORT FUNCTION, Q, OF THE DEEPEST TABULATED DEPTH
C     (PRESSURE) LEVEL OF THE STATION STD CAST, RELATIVE TO THE SURFACE,
C     WITH INCREMENTAL SUMMATIONS INCLUDED FOR SUBSEQUENT DETERMINATION
C     OF THESE VALUES FOR ANY CHOSEN LEVEL RELATIVE TO ANY REFERENCE
C     LEVEL DESIRED BY THE METHODS OF MCLELLAN (1965) AND OTHERS.
C
C     THIS PROGRAM ALSO INCLUDES OPTIONAL ROUTINES FOR OUTPUT OF VALUES
C     OF THE ABOVE CHARACTERISTICS INTERPOLATED AT SELECTED STANDARD
C     DEPTHS (TO THE 1000 M/DB LEVEL SPECIFICALLY), WITH THE CONDITION
C     THAT THE STD CAST MUST REACH 1000+ METERS TO OUTPUT DYNAMIC HEIGHT
C     AND TRANSPORT POTENTIAL OF THE SURFACE RELATIVE TO THAT LEVEL FOR
C     A PARTICULAR STATION.
C
C     ALSO PROGRAMMED ARE ROUTINES YIELDING DEPTHS OF SIGMA-T FROM 23.0
```

```
C      TO 28.0 AT 0.2 INTERVALS, DEPTH OF 22 DEG ISOTHERM, MAX. AND MIN.
C      SALINITIES AND THEIR DEPTHS AND TEMPERATURES, AND DEPTHS OF
C      36.000 PPT SALINITIES. THESE ROUTINES ARE INDEXED BY COMMENT
C      CARDS WITH THEIR TITLES AT THEIR LOCATION WITHIN THE PROGRAM.
C
C      THESE SECONDARY ROUTINES PROVIDE SIGNAL INDICES FOR RAPID
C      ORGANIZATION OF A LARGE NUMBER OF STATIONS, AND ALSO YIELD
C      SPECIFIC DATA IN TABULAR FORM READY FOR MANUAL GRAPHIC TREATMENT.
C
C      SPECIAL CATEGORIZATION OF THE WATER MASS AT EACH STATION AS
C      EITHER RIGHT-HAND OR LEFT-HAND WATER (STATION POSITION RELATIVE
C      TO THE GULF OF MEXICO LOOP CURRENT CORE), IS BASED ON THE
C      MAGNITUDE OF THE MAXIMUM SALINITY VALUE SCANNED. DELINEATION FOR
C      THIS STUDY IS 36.400.
C
C      ROUTINES FOR DELTA (S,P) AND (T,P) CORRECTIONS ARE BASED ON
C      LEAST SQUARES FIT OF TABLE DATA (SVERDRUP, 1933), WITH LINEAR
C      COEFFICIENTS FOR EACH WHOLE VALUE OF TEMPERATURE (3-30 DEG C)
C      AND SALINITY (30-40 PPT) EMPLOYED. LINEAR INTERPOLATION IS
C      UTILIZED TO DETERMINE THE CORRECTION FOR INTERMEDIATE ARGUMENTS.
C
C      KG, COEFFICIENT OF CONDUCTIVITY AS F(TEMPERATURE), UTILIZES A
C      LEAST SQUARES POLYNOMIAL (QUADRATIC) SET OF COEFFICIENTS FOR
C      COMPUTATION AT INDICATED TEMPERATURES.
C
C      IN THIS PROGRAM ZONE ONE IS FROM 0-315 METERS, WITH A DEPTH
C      INTERVAL OF 15 METERS, AND ZONE TWO IS FROM 300-1200 (1500)
C      METERS, AT 75 METER DEPTH INTERVALS.
C      IF THE DEPTH INTERVAL IS CONSTANT FOR THE ENTIRE CAST, THE SECOND
C      ZONE WILL NOT BE USED (SEE STATION HEADER AND DATA CARD FORMAT
C      REMARKS).
C
C      THERE MUST BE AT LEAST THREE POINTS IN ZONE ONE, I.E., 0, 15, AND
C      30 METER LEVELS, FOR OUTPUT TO BE COMPUTED FOR A STATION.
C
```

```
C     THERE MUST BE AT LEAST THREE POINTS (I.E., 300, 375, AND 450
C     METER LEVELS) IN ZONE TWO. IF NOT, DO NOT - REPEAT NOT - PUNCH
C     DATA FOR ZONE TWO.
C
C     *****  STATION HEADER CARD AND DATA FORMAT  *****
C
C     COLS. IDENTIFICATION    REMARKS                                FORMAT
C
C       1-6 STATION NO.       ALPHAMERIC (RIGHT ADJUSTED)              A6
C       7-9 LATITUDE (28-)     -DO-, WHOLE DEGREES                     A3
C     10-14   -DO- (18.3N)     -DO-, MINUTES, SECS AS TENTHS, N/S      A5
C     15-18 LONGITUDE (155-)   -DO-, WHOLE DEGREES                     A4
C     19-23   -DO- (03.0W)     -DO-, MINUTES, SECS AS TENTHS, E/W      A5
C     24-25 DAY (09)          NUMERIC (INTEGER)                        I2
C     26-28 MONTH (AUG)       ALPHAMERIC, ABBREVIATED                  A3
C     29-30 YEAR (66)         NUMERIC (INTEGER)                        I2
C     31-34 TIME (0945)        -DO-, GMT                               I4
C     35-37 NO. OF DATA        -DO-, MAXIMUM 250                       I3
C             POINTS ZONE 1
C     38-40 NO. OF DATA        -DO-, MAXIMUM 250                       I3
C             POINTS ZONE 2
C     41-44 STARTING DEPTH     -DO-, PUNCH DECIMAL, MAX 99.9         F4.1
C             ZONE 1
C     45-50 STARTING DEPTH     -DO-, PUNCH DECIMAL, MAX 9999.9       F6.1
C             ZONE 2
C     51-55 DEPTH INTERVAL     -DO-, PUNCH DECIMAL, MAX 999.9        F5.1
C             ZONE 1
C     56-60 DEPTH INTERVAL     -DO-, PUNCH DECIMAL, MAX 999.9        F5.1
C             ZONE 2
C     61-64 DEPTH OF CAST      -DO- (INTEGER)                          I4
C             METERS
C     65-69 SOUNDING, FATHOMS  -DO- (INTEGER)                          I5
C
C     STARTING DEPTHS ARE USED WITHIN THE PROGRAM TO CONTROL THE DEPTH
C     AT WHICH TABULATED OUTPUT BEGINS FOR EACH ZONE, WITH SUBSEQUENT
```

```
C       DEPTH LEVELS WITHIN EACH ZONE DETERMINED BY THE DEPTH INTERVAL
C       WITHIN THAT ZONE. THE PROGRAM IS SO ARRANGED THAT TABULAR OUTPUT
C       OF THE S/T/D CAST RETAINS CONTINUITY AT THE ZONE BREAK.
C            NOTE THAT THE CORRECTION FORMULA FOR SALINITY INVOLVES THE
C       PARTIAL DERIVATIVE OF TEMPERATURE WITH DEPTH. EITHER A FORWARD
C       DIFFERENCE OR CENTRAL DIFFERENCE OPERATOR MAY BE USED. THIS
C       PROGRAM UTILIZES THE C.D.O. FOR DT/DZ, THEREFORE THE LAST DATA
C       POINT IN ZONE 1 AND THE FIRST DATA POINT IN ZONE 2 ARE FOR
C       COMPUTATIONAL USE ONLY AND DO NOT APPEAR IN OUTPUT. THIS SHOULD
C       BE CONSIDERED WHEN DETERMINING DEPTH SPANS OF ZONES 1 AND 2. THE
C       PROGRAM MAY BE USED FOR ONE ZONE ONLY (DEPTH INTERVAL OF DATA
C       POINTS CONSTANT THROUGHOUT CAST RANGE), IN WHICH CASE THE DATA
C       WOULD BE ASSOCIATED WITH ZONE 1 INDICES ONLY, WITH ZONE 2 INDICES
C       SET EQUAL TO ZEROES.
C
C       TEMPERATURE AND SALINITY DATA UTILIZE THE SAME FORMAT -F5.2- WITH
C       A MAXIMUM OF 15 POINTS PER CARD. FALL RATE (OF SENSOR UNIT THROUGH
C       THE WATER) HAS FORMAT F5.3, ALSO WITH 15 POINTS PER CARD MAXIMUM.
C       COLUMN IDENTIFICATION OF DATA CARDS FOR ALL THREE ARE THE SAME,
C       E.G., 1-4 ARE BLANK, FOLLOWED BY 15 FIELDS OF 5 SPACES EACH.
C       TEMPERATURE, SALINITY, AND FALL RATE (IN METERS/SECOND) ARE READ
C       AND PUNCHED AS FOUR INTEGERS, RIGHT ADJUSTED INTO THE FIVE-SPACE
C       FIELDS, THEREFORE TWO DECIMAL PLACE READINGS, FOR TEMPERATURE AND
C       SALINITY, AND THREE PLACES FOR FALL RATE, ARE ALLOWABLE. DATA
C       ACCURATE TO ONLY ONE DECIMAL SHOULD BE PUNCHED WITH A ZERO IN THE
C       SECOND DECIMAL PLACE, OR, ALTERNATELY, NEW FORMATS MAY BE USED.
C       ALL DATA FOR SALINITY, TEMPERATURE, AND FALL RATE FOR EACH ZONE
C       ARE PUNCHED SEQUENTIALLY FROM TOP TO BOTTOM.
C
C      *****ORDER OF DATA CARDS FOR STATIONS*****
C       STATION HEADER CARD
C       SALINITIES  ZONE ONE
C       TEMPERATURES  ZONE ONE
C       FALL VELOCITY  ZONE ONE
C       SALINITIES  ZONE TWO
```

```
C      TEMPERATURES  ZONE TWO
C      FALL VELOCITIES  ZONE TWO
C      .....ETCETERA.....
C
C
C
       DIMENSIONT(250),SI(250),SC(250),FALL(250),DSAL(250),SIGT(250),THER
      1M(250),Z(250),AINC(26),DE(26,5),DS(6),TT(6)
       DIMENSIONDELTP(250),TABT(15),TABS(15),COEFTA(15),COEFTB(15),COEFSA
      1(15),COEFSB(15),DELSP(250),AVGDEL(250),PROD(250),PINT(250),DYNZ(25
      20),DEL(250),Q(250),DBARDZ(250)
       DIMENSIONXZ(18),XT(18),XSC(18),XSIGT(18),XTHERM(18),XDEL(18),XAVDE
      1L(18),XPROD(18),XPINT(18),XDYNZ(18),XDBARZ(18),XQ(18)
       REAL KG,KR
       INTEGER DAY,YEAR,TIME
C
C
C      READ IN STANDARD DEPTH LEVELS
C
C
       READ(5,925)(XZ(I),I=1,18)
  925 FORMAT(13F6.0)
C
C
C      READ IN ARRAY AINC
C
C
       AINC(1)=23.0
       DO40KZ=2,26
   40 AINC(KZ)=AINC(KZ-1)+0.2
C
C
C      READ IN TABS, TABT, COEFSA/B, COEFTA/B
C
C
```

```
      READ(5,30)(TABS(I),I=1,11)
      READ(5,30)(TABT(I),I=1,12)
   30 FORMAT(12F5.1)
      READ(5,31)(COEFSA(I),COEFSB(I),I=1,11)
      READ(5,31)(COEFTA(I),COEFTB(I),I=1,12)
   31 FORMAT(2E20.8)
C
C
C     READ STATION IDENTIFYING DATA
C
C
  600 READ(5,100)STATIO ,ALAT1 ,ALAT2 ,ALONG1,ALONG2,DAY,AMONTH,YEAR,TIM
     1E,NP1,NP2,START1,START2,DZ1,DZ2,IBOT,IFATH
  100 FORMAT(A6,A3,A5,A3,A5,I2,A3,I2,I4,2(I3),F4.1,F6.1,2(F5.1),I4,I5)
      TIME=TIME+10000
C
      WRITE(6,301)STATIO ,ALAT1 ,ALAT2 ,ALONG1,ALONG2,DAY,AMONTH,YEAR,TI
     1ME,IBOT,IFATH
  301 FORMAT(1H1,56X,7HSTATION,3X,A6,/,56X,A3,A5,2X,A3,A5,/,61X,I2,1X,A3
     1,1X,I2,/,62X,I4,3HGMT,/,54X,11HCAST DEPTH ,I4,7H METERS,/,54X,9HSO
     2UNDING ,I5,8H FATHOMS,/)
C
C
C     TABULAR HEADING FORMAT FOR MINIMUM OUTPUT
C
C
      WRITE(6,302)
  302 FORMAT(1H0,///,5X,6H DEPTH,1X,5H TEMP,1X,8HCORR SAL,1X,7HIND SAL,1
     1X,8HDIFF SAL,1X,7HSIGMA-T,4X,5HTHERM,1X,5HDELTP,1X,5HDELSP,1X,8H D
     2ELTA  ,1X,8HAVG DEL ,1X,9HAVG DEL *,1X,9H DYNAMIC ,1X,7HAVGDYHT,1X
     3,7HQ TRANS,/,5X,6HMETERS,1X,5HDEG C,1X,8H  0/00  ,1X,7H 0/00  ,1X,
     48H  0/00  ,12X,5HX10+5,1X,5HX10+5,1X,5HX10+5,1X,8H X10+5  ,1X,8H X
     510+5  ,1X,9HPRESS INT,1X,9H  DEPTH  ,1X,7H  *DZ  ,1X,7H FUNCT ,///
     6)
C
```

```
C
C     ZERO ARRAY DE/DS/TT
C
C
      DO 401 MR = 1,5
      DO 401 MC = 1,26
      DE(MC,MR) = 0.0
  401 CONTINUE
      DO 701 MR = 1,6
      DS(MR)=0.0
      TT(MR)=0.0
  701 CONTINUE
C
C
      DTAU=0.35
      ALPHA=0.38010940E-01
      BETA= 0.29435027E-01
      GAMMA=-0.55660979E-04
C
      N=1
      M=NP1
      MM=M-1
      DEEP=START1
      DZ=DZ1
      K=1
      GOTO501
  500 N=NP1+2
      M=NP1+NP2
      MM=M
      DEEP=START2
      DZ=DZ2
      K=NP1+1
      IF(NP2.EQ.0)GOTO601
      IF(K.GT.M)GOTO601
C
```

```
C
C     READ SALINITY, TEMPERATURE, AND FALL RATE FOR ZONES ONE AND TWO
C
C
  501 CONTINUE
      READ(5,101)(SI(I),I=K,M)
      READ(5,101)(T(I),I=K,M)
  101 FORMAT(4X,15F5.2)
      READ(5,102)(FALL(I),I=K,M)
  102 FORMAT(4X,15F5.3)
      DO 10 I=N,MM
      IF(I.EQ.M)GOTO55
      IF(I-1)505,52,53
   52 DTDZ=(T(I+1)-T(I))/DZ
      GOTO54
   53 DTDZ=(T(I+1)-T(I-1))/(2.*DZ)
      GOTO54
   55 DTDZ=(T(I)-T(I-1))/DZ
   54 CONTINUE
      CON=DTAU*FALL(I)
      KR=(ALPHA+BETA*SI(I)+GAMMA*(SI(I)**2.))/(BETA*SI(I)+2.*GAMMA*(SI(I
     1)**2.))
C     CALL ON FUNCTION SUBPROGRAM FOR CONDUCTIVITY COEFFICIENT
      KG=CURV(T,I)
      SC(I)=(SI(I))*(1.-(KR*KG*DTDZ*CON))
      DSAL(I)=SC(I)-SI(I)
      CLORF=(SC(I)-0.030)/1.8050
      SIGO=(((3.98E-5)*CLORF-1.57E-3)*CLORF+1.4708)*CLORF-0.069
      SIGT(I)=-((T(I)-3.98)**2)*(T(I)+283.0)/(503.570*(T(I)+67.26))+(SIG
     10+0.1324)*(1.-(((0.0010843*T(I)-0.098185)*T(I)+4.7867)*T(I)*0.001)
     2+(SIGO-0.1324)*(((0.01667*T(I)-0.8164)*T(I)+18.030)*T(I)*(1.E-6)))
      THERM(I)=((1.-0.972643)-((SIGT(I)*0.001)/(1.+SIGT(I)*0.001)))*(1.E
     1+5)
      Z(I)=DEEP
      DEEP=Z(I)+DZ
```

```
   10 CONTINUE
      IF(N.LE.1)GOTO500
  601 CONTINUE
C
C
C     ARRANGE SELECTED QUANTITIES IN CONSECUTIVE ORDER OF LEVEL
C
C
      IF(NP2.LT.3)GOTO999
      K=NP1
      I1=K+2
      I2=K+NP2
      DO 99 I=I1,I2
      Z(K)=Z(I)
      SIGT(K)=SIGT(I)
      T(K)=T(I)
      SC(K)=SC(I)
      SI(K)=SI(I)
      DSAL(K)=DSAL(I)
      THERM(K)=THERM(I)
      K=K+1
   99 CONTINUE
  999 CONTINUE
C
C
C     DELTA (S,P) CORRECTION
C
C
      IF(NP2.LT.3)GOTO62
      IM2=NP1+NP2-2
      GOTO67
   62 IM2=NP1-1
   67 CONTINUE
      IF(IM2.LT.1)GOTO60
      DO 65 I = 1,IM2
```

```
      DO 66 J = 1,10
      IF(Z(I).EQ.0.0)GOTO61
      IF(SC(I).LT.TABS(J))GOTO63
      IF(SC(I).GT.TABS(J+1))GOTO63
      GOTO64
   63 IF(SC(I).GT.TABS(J))GOTO66
      IF(SC(I).LT.TABS(J+1))GOTO66
      GOTO64
   64 A1=COEFSA(J)
      A2=COEFSA(J+1)
      B1=COEFSB(J)
      B2=COEFSB(J+1)
      CORS1=(Z(I)-B1)/A1
      CORS2=(Z(I)-B2)/A2
      DELSP(I)=CORS1-(((CORS1-CORS2)*(TABS(J)-SC(I)))/(TABS(J)-TABS(J+1)
     1))
      GOTO65
   66 CONTINUE
      GOTO65
   61 DELSP(I)=0.0
   65 CONTINUE
   60 CONTINUE
C
C     DELTA (T,P) CORRECTION
C
      IF(IM2.LT.1)GOTO20
      DO 25 I = 1,IM2
      DO 22 J = 1,11
      IF(Z(I).EQ.0.0)GOTO21
      IF(T(I).GT.30.0)GOTO21
      IF(T(I).LT.TABT(J))GOTO23
      IF(T(I).GT.TABT(J+1))GOTO23
      GOTO24
   23 IF(T(I).GT.TABT(J))GOTO22
      IF(T(I).LT.TABT(J+1))GOTO22
```

```
      GOTO24
   24 A1=COEFTA(J)
      A2=COEFTA(J+1)
      B1=COEFTB(J)
      B2=COEFTB(J+1)
      CORT1=(Z(I)-B1)/A1
      CORT2=(Z(I)-B2)/A2
      DELTP(I)=CORT1-(((CORT1-CORT2)*(TABT(J)-T(I)))/(TABT(J)-TABT(J+1))
     1)
      GOTO25
   22 CONTINUE
      GOTO25
   21 DELTP(I)=0.0
   25 CONTINUE
   20 CONTINUE
C
C     COMPUTING DYNAMIC DEPTHS
C
      DO 71 I = 1,IM2
      DEL(I)=THERM(I)+DELTP(I)+DELSP(I)
   71 CONTINUE
      AVGDEL(IM2)=0.0
      PROD(IM2)=0.0
      PINT(IM2)=0.0
      DBARDZ(IM2)=0.0
      DYNZ(1)=0.0
      Q(1)=0.0
      IF(NP2.LT.3)GOTO75
      IM3=NP1+NP2-3
      IM5=IM3
      GOTO76
   75 IM3=NP1-1
      IM5=NP1-2
   76 CONTINUE
      DO 72 I = 1,IM5
```

```
      J=I+1
      AVGDEL(I)=(DEL(I)+DEL(J))/2.0
      PINT(I)=Z(J)-Z(I)
      PROD(I)=(AVGDEL(I))*(PINT(I))*(1.0E-5)
      DYNZ(J)=DYNZ(I)+PROD(I)
      DBARDZ(I)=((DYNZ(I)+DYNZ(J))/2.0)*(PINT(I))
      Q(J)=Q(I)+DBARDZ(I)
   72 CONTINUE
C
      DO 70 I = 1,IM2
      WRITE(6,303)Z(I),T(I),SC(I),SI(I),DSAL(I),SIGT(I),THERM(I),DELTP(I
     1),DELSP(I),DEL(I),AVGDEL(I),PROD(I),DYNZ(I),DBARDZ(I),Q(I)
  303 FORMAT(1H ,4X,F6.1,1X,F5.2,1X,F8.3,1X,F7.3,1X,F8.3,1X,F7.2,1X,F8.2
     1,1X,F5.2,1X,F5.2,1X,F8.2,1X,F8.2,1X,F9.5,1X,F9.5,1X,F7.2,1X,F8.2)
   70 CONTINUE
      WRITE(6,111)
  111 FORMAT(1H0,///)
C
C     ****************************************************
C     *****  STANDARD DEPTH INTERPOLATION ROUTINE  *****
C     ****************************************************
C
C     ESTABLISHING MAXIMUM STANDARD DEPTH INCLUDED IN THIS STATION
C     S/T/D CAST FOR WHICH INTERPOLATION CAN BE ACCOMPLISHED
C
C     THE INDEX, K9, IS DETERMINED BASED ON
C          (1) THERE MUST BE AT LEAST TWO DATA LEVELS BELOW THE STANDARD
C     DEPTH FOR WHICH A COMPUTATION IS MADE (IN ORDER FOR THE
C     LAGRANGIAN INTERPOLATION FORMULA TO YIELD CORRECT RESULTS), AND
C          (2) FOR CASTS GREATER THAN 1000 METERS, THERE MUST BE TWO
C     DATA LEVELS BELOW 1000 METERS IN ORDER THAT DYNAMIC HEIGHTS AND
C     TRANSPORT POTENTIAL RELATIVE TO THE 1000 DB REFERENCE LEVEL MAY
C     BE COMPUTED (SEE STATEMENT -DCHECK- FOLLOWING STATEMENT NO. 9111).
C
      K9=18
```

```
      DO 201 K1 = 1,18
      IF(Z(IM2-1).GT.XZ(K1))GOTO201
      IF(Z(IM2-1).EQ.XZ(K1))GOTO203
      IF(Z(IM2).EQ.XZ(K1))GOTO203
  202 K9=K1-1
      GOTO204
  203 K9=K1
      GOTO204
  201 CONTINUE
  204 CONTINUE
C
C
      DO 9111 KL = 1, K9
      DO 911 KK = 1, IM3
      IF(XZ(KL).EQ.Z(KK))GOTO913
      IF(XZ(KL).GT.Z(KK))GOTO912
      IF(XZ(KL).LT.Z(KK+1))GOTO912
      GOTO914
  912 IF(XZ(KL).LT.Z(KK))GOTO911
      IF(XZ(KL).GT.Z(KK+1))GOTO911
      IF(XZ(KL).EQ.Z(KK+1))GOTO913
      GOTO914
  914 IF((KK-1).LT.1)GOTO915
C
C     OBSERVED DEPTH NOT EQUAL STANDARD DEPTH
C
      Z1=Z(KK-1)
      Z2=Z(KK)
      Z=XZ(KL)
      Z3=Z(KK+1)
      Z4=Z(KK+2)
      T1=T(KK-1)
      T2=T(KK)
      T3=T(KK+1)
      T4=T(KK+2)
```

```
      S1=SC(KK-1)
      S2=SC(KK)
      S3=SC(KK+1)
      S4=SC(KK+2)
C
C     LAGRANGIAN INTERPOLATION OF TEMP AND SALINITY (4-POINT)
C
      XT(KL)=((T1*(Z-Z2)*(Z-Z3))/((Z1-Z2)*(Z1-Z3))+(T2*(Z-Z1)*(Z-Z3))/((
     1Z2-Z1)*(Z2-Z3))+(T3*(Z-Z1)*(Z-Z2))/((Z3-Z1)*(Z3-Z2))+(T2*(Z-Z3)*(Z
     2-Z4))/((Z2-Z3)*(Z2-Z4))+(T3*(Z-Z2)*(Z-Z4))/((Z3-Z2)*(Z3-Z4))+(T4*(
     3Z-Z2)*(Z-Z3))/((Z4-Z2)*(Z4-Z3)))*0.5
      XSC(KL)=((S1*(Z-Z2)*(Z-Z3))/((Z1-Z2)*(Z1-Z3))+(S2*(Z-Z1)*(Z-Z3))/(
     1(Z2-Z1)*(Z2-Z3))+(S3*(Z-Z1)*(Z-Z2))/((Z3-Z1)*(Z3-Z2))+(S2*(Z-Z3)*(
     2Z-Z4))/((Z2-Z3)*(Z2-Z4))+(S3*(Z-Z2)*(Z-Z4))/((Z3-Z2)*(Z3-Z4))+(S4*
     3(Z-Z2)*(Z-Z3))/((Z4-Z2)*(Z4-Z3)))*0.5
      GOTO916
C
C     LINEAR INTERPOLATION OF TEMP AND SALINITY
C
  915 XT(KL)=T(KK)-((T(KK)-T(KK+1))*(XZ(KL)-XZ(KL-1))/(Z(KK+1)-Z(KK)))
      XSC(KL)=SC(KK)-((SC(KK)-SC(KK+1))*(XZ(KL)-XZ(KL-1))/(Z(KK+1)-Z(KK)
     1))
C
C     COMPUTATION OF SIGMA-T, THERMOSTERIC ANOMALY, AND DELTA
C     AT INTERPOLATED STANDARD DEPTH TEMP AND SALINITY VALUES
C
  916 CLORF=(XSC(KL)-0.030)/1.8050
      SIGO=(((3.98E-5)*CLORF-1.57E-3)*CLORF+1.4708)*CLORF-0.069
      XSIGT(KL)=-((XT(KL)-3.98)**2)*(XT(KL)+283.0)/(503.570*(XT(KL)+67.2
     16))+(SIGO+0.1324)*(1.-(((0.0010843*XT(KL)-0.098185)*XT(KL)+4.7867)
     2*XT(KL)*0.001)+(SIGO-0.1324)*(((0.01667*XT(KL)-0.8164)*XT(KL)+18.0
     330)*XT(KL)*(1.E-6)))
      XTHERM(KL)=((1.-0.972643)-((XSIGT(KL)*0.001)/(1.+XSIGT(KL)*0.001))
     1)*(1.E+5)
C
```

```
C       XDELTA (S,P) ROUTINE - STANDARD DEPTHS
C
        DO 6601 J = 1,10
        IF(XZ(KL).EQ.0.0)GOTO6101
        IF(XSC(KL).LT.TABS(J))GOTO6301
        IF(XSC(KL).GT.TABS(J+1))GOTO6301
        GOTO6401
 6301   IF(XSC(KL).GT.TABS(J))GOTO6601
        IF(XSC(KL).LT.TABS(J+1))GOTO6601
        GOTO6401
 6401   A1=COEFSA(J)
        A2=COEFSA(J+1)
        B1=COEFSB(J)
        B2=COEFSB(J+1)
        CORS1=(XZ(KL)-B1)/A1
        CORS2=(XZ(KL)-B2)/A2
        XDELSP=CORS1-(((CORS1-CORS2)*(TABS(J)-XSC(KL)))/(TABS(J)-TABS(J+1)
       1))
        GOTO6501.
 6601   CONTINUE
        GOTO6501
 6101   XDELSP=0.0
 6501   CONTINUE
C
C       XDELTA (T,P) ROUTINE - STANDARD DEPTHS
C
        DO 2201 J = 1,11
        IF(XZ(KL).EQ.0.0)GOTO2101
        IF(XT(KL).GT.30.0)GOTO2101
        IF(XT(KL).LT.TABT(J))GOTO2301
        IF(XT(KL).GT.TABT(J+1))GOTO2301
        GOTO2401
 2301   IF(XT(KL).GT.TABT(J))GOTO2201
        IF(XT(KL).LT.TABT(J+1))GOTO2201
        GOTO2401
```

```
 2401 A1=COEFTA(J)
      A2=COEFTA(J+1)
      B1=COEFTB(J)
      B2=COEFTB(J+1)
      CORT1=(XZ(KL)-B1)/A1
      CORT2=(XZ(KL)-B2)/A2
      XDELTP=CORT1-(((CORT1-CORT2)*(TABT(J)-XT(KL)))/(TABT(J)-TABT(J+1))
     1)
      GOTO2501
 2201 CONTINUE
      GOTO2501
 2101 XDELTP=0.0
 2501 CONTINUE
      XDEL(KL)=XTHERM(KL)+XDELSP+XDELTP
      GOTO9111
C
C     OBSERVED DEPTH EQUAL STANDARD DEPTH - TEMP, SAL, SIGMA-T,
C     THERMOSTERIC ANOMALY, AND DELTA SAME AS OBSERVED
C
  913 IF(XZ(KL).EQ.0.0)GOTO9131
      KKK=KK+1
      GOTO9132
 9131 KKK=KK
 9132 XT(KL)=T(KKK)
      XSC(KL)=SC(KKK)
      XSIGT(KL)=SIGT(KKK)
      XTHERM(KL)=THERM(KKK)
      XDEL(KL)=DEL(KKK)
      GOTO9111
  911 CONTINUE
 9111 CONTINUE
C
C     DETERMINE IF DYNAMIC HEIGHT AND Q RELATIVE TO 1000 DB LEVEL
C     CAN BE COMPUTED FOR THIS CAST
C
```

```
      DCHECK=1000.0 + 2.0*DZ2
      IF(Z(IM2).LT.DCHECK)GOTO917
C
C     COMPUTE DYNAMIC HEIGHT AND TRANSPORT FUNCTION, Q
C
      XAVDEL(1)=0.0
      XPROD(1)=0.0
      XPINT(1)=0.0
      DO 7201 KL = 1,17
      XAVDEL(KL+1)=(XDEL(KL)+XDEL(KL+1))/2.0
      XPINT(KL+1)=XZ(KL+1)-XZ(KL)
      XPROD(KL+1)=(XAVDEL(KL+1))*(XPINT(KL+1))*(1.0E-5)
 7201 CONTINUE
      XDYNZ(18)=0.0
      DO 8101 I = 1,17
      KL = 18 - I
      XDYNZ(KL)=XDYNZ(KL+1)+XPROD(KL+1)
 8101 CONTINUE
      XDBARZ(1)=0.0
      DO 8201 KL = 1,17
      XDBARZ(KL+1)=((XDYNZ(KL)+XDYNZ(KL+1))/2.0)*(1.0E+1)*(XPINT(KL+1))
 8201 CONTINUE
      XQ(18)=0.0
      DO 8301 I = 1,17
      KL = 18 - I
      XQ(KL)=XQ(KL+1)+XDBARZ(KL+1)
 8301 CONTINUE
      GOTO919
  917 WRITE(6,1917)
 1917 FORMAT(1H0,/,5X,101HVALUES AT STANDARD DEPTHS LESS DYNAMIC HEIGHT
     1AND TRANSPORT POTENTIAL (1000 DB REF LEVEL NOT REACHED),//,5X,6H D
     2EPTH,1X,6H  TEMP,1X,8HSALINITY,1X,7HSIGMA-T,1X,7H  THERM,//)
      DO 2918 I = 1,K9
      WRITE(6,918)XZ(I),XT(I),XSC(I),XSIGT(I),XTHERM(I)
  918 FORMAT(1H ,4X,F6.1,1X,F6.2,1X,F8.3,1X,F7.2,1X,F7.2)
```

```
 2918 CONTINUE
      GOTO2000
  919 WRITE(6,1919)
 1919 FORMAT(1HO,/,5X,105HVALUES AT STANDARD DEPTHS WITH DYNAMIC HEIGHT
     1AND TRANSPORT POTENTIAL RELATIVE TO 1000 DB REFERENCE LEVEL,//,5X,
     26H DEPTH,1X,6H  TEMP,1X,8HSALINITY,1X,7HSIGMA-T,1X,7H  THERM,1X,9H
     3DYN HT, M,1X,7HQ TRANS,//)
      DO 2920 I = 1,18
      WRITE(6,920)XZ(I),XT(I),XSC(I),XSIGT(I),XTHERM(I),XDYNZ(I),XQ(I)
  920 FORMAT(1H ,4X,F6.1,1X,F6.2,1X,F8.3,1X,F7.2,1X,F7.2,1X,F9.5,1X,F7.1
     1)
 2920 CONTINUE
 2000 CONTINUE
C
C     ****************************************************************
C     *****  STANDARD DEPTH INTERPOLATION ROUTINE COMPLETED  *****
C     ****************************************************************
C
      WRITE(6,111)
C
C
C     DETERMINE DEPTHS OF SELECTED SIGMA-T
C
C
      L=1
      IF(NP2.LT.3)GOTO1401
      IM4=IM3
      GOTO1402
 1401 IM4=IM3-1
 1402 CONTINUE
      IF(IM3.LT.1)GOTO451
      DO 411 KL = 1,26
      DO 411 KK = 1, IM4
      IF(AINC(KL).GT.SIGT(KK))GOTO412
      IF(AINC(KL).LT.SIGT(KK+1))GOTO412
```

```
      GOTO414
  412 IF(AINC(KL).LT.SIGT(KK))GOTO411
      IF(AINC(KL).GT.SIGT(KK+1))GOTO411
      GOTO414
  414 IF(DE(KL,L).NE.0.)L=L+1
      IF(DE(KL,L).NE.0.)GOTO414
      IF(L.EQ.6)L=5
      DE(KL,L)=(Z(KK)-Z(KK+1))/(SIGT(KK)-SIGT(KK+1))*(AINC(KL)-SIGT(KK+1
     1))+Z(KK+1)
      L=1
  411 CONTINUE
      WRITE(6,901)
  901 FORMAT(1H ,11X,17HDEPTHS OF SIGMA-T,//)
      DO 450 KQ = 1,26
      WRITE(6,331)AINC(KQ),(DE(KQ,NN),NN=1,5)
  331 FORMAT(1H ,10X,F7.2,5(5X,F8.1))
  450 CONTINUE
  451 CONTINUE
C
C
C     DETERMINE DEPTHS OF 36.000 PPT SALINITY
C     .....INTERPOLATED TEMPERATURES DETERMINED.....
C
C
      L=1
      LL=0
      IF(IM3.LT.1)GOTO702
      WRITE(6,7311)
 7311 FORMAT(1H0,/,10X,32HLOCATIONS OF 36.000 PPT SALINITY)
      DO 711 KK = 1,IM3
      IF(36.0.GT.SC(KK))GOTO712
      IF(36.0.LT.SC(KK+1))GOTO712
      GOTO714
  712 IF(36.0.LT.SC(KK))GOTO711
      IF(36.0.GT.SC(KK+1))GOTO711
```

```
      GOTO714
  714 IF(DS(L).NE.0.)L=L+1
      IF(DS(L).NE.0.)GOTO714
      IF(L.EQ.7)L=6
      DS(L)=(Z(KK)-Z(KK+1))/(SC(KK)-SC(KK+1))*(36.0-SC(KK+1))+Z(KK+1)
      TT(L)=(T(KK)-T(KK+1))/(SC(KK)-SC(KK+1))*(36.0-SC(KK+1))+T(KK+1)
      L=1
      LL=LL+1
  711 CONTINUE
      WRITE(6,731)(NN,DS(NN),TT(NN),NN=1,LL)
  731 FORMAT(1H ,/,20X,7HLEVEL (,I2,2H) ,/,20X,5HDEPTH,5X,F8.2,/,20X,4HT
     1EMP,6X,F8.2)
  702 CONTINUE
      IF(IM2.LT.1)GOTO600
C
C
C     DEPTH OF MAXIMUM SALINITY AND ITS VALUE AND TEMPERATURE
C
C
      HOLD=0.0
      DO 551 I=1,IM2
      IF(SC(I).GT.HOLD)GOTO552
      GOTO551
  552 HOLD=SC(I)
      IHOLD=I
  551 CONTINUE
      WRITE(6,333)HOLD,Z(IHOLD),T(IHOLD)
  333 FORMAT(1H0,/,10X,12HMAX SALINITY,F7.3,/,10X,13HDEPTH        ,F6.2,
     1/,10X,13HTEMP         ,F6.2)
C
C
C     DETERMINATION OF MINIMUM SALINITY AND ITS DEPTH AND TEMPERATURE
C     THIS ROUTINE REQUIRES HOLD AND IHOLD FROM SAL MAX ROUTINE
C
C
```

```
      DMAXS=Z(IHOLD)
      STORE=HOLD
      DO 1 I = 1,IM2
      IF(SC(I).LT.STORE)GOTO2
      GOTO1
    2 DMINS=Z(I)
      IF(DMINS.GT.DMAXS)GOTO3
      GOTO1
    3 STORE=SC(I)
      ISTORE=I
    1 CONTINUE
      WRITE(6,4)STORE,DMINS,T(ISTORE)
    4 FORMAT(1H0,/,10X,12HMIN SALINITY,F7.3,/,10X,13HDEPTH        ,F6.2,
     1/,10X,13HTEMP         ,F6.2)
C
C
C     DETERMINE DEPTH OF 22 DEG ISOTHERM
C
C
      DO 555 I=1,IM2
      IF(T(I).GT.22.0)GOTO555
      IF(T(I).EQ.22.0)GOTO556
      IF(T(I).LT.22.0)GOTO557
  555 CONTINUE
      GOTO89
  557 DT=Z(I-1)-(((T(I-1)-22.0)/(T(I-1)-T(I)))*(Z(I-1)-Z(I)))
      GOTO558
  556 DT=Z(I)
  558 WRITE(6,332)DT
  332 FORMAT(1H0,/,10X,25HDEPTH OF 22 DEG ISOTHERM ,F15.2,7H METERS)
      GOTO88
   89 WRITE(6,87)IBOT
   87 FORMAT(1H ,/,10X,25H22 DEG ISOTHERM IS BELOW ,I4,24H METERS AT THI
     1S STATION.)
   88 CONTINUE
```

```
C
C
      IF(DT.LT.150.0)GOTO8020
      IF(HOLD.GE.36.4)GOTO801
 8020 WRITE(6,802)
  802 FORMAT(1H0,30X,26H*****LEFT  HAND WATER*****)
      GOTO888
  801 WRITE(6,804)
  804 FORMAT(1H0,30X,26H*****RIGHT HAND WATER*****)
  888 CONTINUE
C
C
      GOTO600
  505 STOP
      END
C
C
C     FUNCTION SUBPROGRAM FOR CONDUCTIVITY FACTOR
$IBFTC SUBA
      FUNCTIONCURV(T,I)
      DIMENSIONT(250)
      A1 = 0.29903286E-01
      A2 = -0.57238591E-03
      A3 = 0.66485782E-05
      POLY=A1 + A2*T(I) + A3*(T(I)**2.)
      CURV=POLY
      RETURN
      END
```

```
$DATA
   0.    10.    20.    30.    50.    75.   100.   125.   150.   200.   250.   300.   400.
  500.  600.   700.   800.  1000.
 40.0 39.0 38.0 37.0 36.0 35.0 34.0 33.0 32.0 31.0 30.0
 30.0 25.0 20.0 15.0 10.0  9.0  8.0  7.0  6.0  5.0  4.0  3.0
      0.13874925E 03     -0.79178435E 01
      0.17253837E 03     -0.11325533E 02
      0.22959051E 03     -0.33437728E 01
      0.34401114E 03     -0.68244442E 01
      0.68006812E 03     -0.23577412E 02
       0.0                0.0
     -0.68006812E 03     -0.23577412E 02
     -0.33783899E 03     -0.59146680E 01
     -0.22215421E 03     -0.48959444E 01
     -0.16666666E 03      0.17935032E-04
     -0.13331863E 03     -0.29748555E 01
      0.24329355E 02     -0.38387557E 01
      0.26120796E 02     -0.31815282E 01
      0.29716459E 02     -0.10555682E 02
      0.35442702E 02     -0.10688981E 02
      0.47613407E 02     -0.88387180E 01
      0.51907910E 02     -0.85042400E 01
      0.57227777E 02     -0.89832977E 01
      0.63961188E 02     -0.91393969E 01
      0.73009768E 02     -0.11583175E 02
      0.85754873E 02     -0.13754437E 02
      0.10413809E 03     -0.12811448E 02
      0.13223267E 03     -0.42041957E 00
```

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